THE OIL SHALE INDUSTRY

COLORADO OIL SHALE

Frontispiece

THE OIL SHALE INDUSTRY

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WITH FIFTEEN ILLUSTRATIONS FROM PHOTOGRAPHS

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PREFACE

To describe an industry which is still in its primary stage is not an easy task. Without definite commercial results to record, without well established processes to describe, and with information on all phases of the subject widely scattered and known only to the particular persons interested, the preparation of the present volume has been difficult. However, the recent striking demand in industrial life for oil in its many forms, the failure of domestic wells to meet this demand in full, the rapid advance in the price of petroleum, the warning of geologists and government experts that the underground supply of oil cannot much longer be depended upon to supply the ever increasing demand, all unite in pointing unerringly to the one permanent supply of the raw material which we have—the deposits of oil shale. Whether we wish it to be so or not, we shall soon be forced to resort to the oil shales for our supply of oil. Regardless of the number and complexity of problems to be solved in establishing the oil shale industry on a commercial basis, yet they must be solved, and it remains for the American mining engineer, chemist, and inventor to provide the solution, else our boasted industrial life will

vanish. The successful retorting of oil from shale and the establishment of the oil shale industry on a permanent and profitable basis is the great problem of this decade. No other phase of our industrial life can compare with it. The finger of fate points towards it.

Methods of investigation, both in the field and in the laboratory, are far from being standardized. The character of the shale, methods of attack, as well as the skill of the experimenter, all combine to make reports of results vary widely. It is hoped that in the near future the scientific principles underlying the treatment of oil shale will be so well understood and the methods of work so well standardized that a proper comparison of results may be made. In the present state of the industry this is impossible.

In order to meet the widespread demand for information of a comprehensive nature this volume has been prepared as a modest contribution. My thanks are due to the many workers, widely scattered, who have contributed in no small degree to our sum total of information, but especially are my thanks due to Professors Albert H. Low, and Clayton W. Botkin of the Department of Chemistry; and John C. Williams, Assistant Director of the Department of Metallurgical Research, of the Colorado School of Mines; also to my secretary, Miss Zelda Margaret Moynahan.

VICTOR C. ALDERSON.

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CHAPTER I

THE DAWN OF A NEW INDUSTRY

The Dawn

Recent years have been filled with stirring and far-reaching events, world wide in their effect, not the least of which has been the birth of a new industry, with a potential supply of raw material that almost defies mathematical computation and staggers the imagination. Can oil wells produce enough petroleum to meet the enormous demand now existing for oil and its products? The answer is doubtful. Will new oil fields be discovered to meet the increased demand in the future? The answer is extremely doubtful. Yet this is the age of oil. Oil we must have. The future supply must come from our great deposits of oil shale. If oil is the "king" then oil shale is the "heir apparent."

The Present Condition of the Petroleum Industry

From 1857 the total of the world production of petroleum was 6,996,674,563 barrels; of this, the United States produced 4,252,644,003 barrels. There are now approximately 250,000 producing oil wells in the United States. The average yield is only four and a half barrels a day. Among the

great producers is the Burkburnett pool in Texas that has produced more than 7,000,000 barrels of oil and the Ranger pool that has produced more than 12,000,000 barrels. The average output in Wyoming is 40 barrels a well per day. The low average for the whole country of only four and a half barrels a day is caused by thousands of wells in the older fields that produce less than a quarter of a barrel a day. Of the total number of wells in the United States four-fifths do not yield more than a barrel of oil daily.

The United States Bureau of Mines recently made a report to the Secretary of the Treasury on the subject in which it said:

Report of the United States Bureau of Mines

"The United States Geological Survey makes the pessimistic report that our underground reserves are forty per cent exhausted and that we probably are near the peak of domestic production. The consumption of petroleum is increasing far more rapidly than domestic production. During 1918, 39,000,000 barrels of oil were imported from foreign countries and 27,000,000 barrels were withdrawn from stocks.

"Our future supply of petroleum must be conserved, and it is therefore imperative that the United States make every possible effort to further more efficient conservation of our underground reserves of oil and the more efficient utilization of petroleum and its products, because:

"First. Petroleum has become the fundamental

basis of the industrial and military life of the nation in that gasoline has become the motive power for six million automobiles and trucks, for airplanes, farm tractors, and motor boats. Fuel oil has become necessary for our navy, our merchant marine, and larger industrial plants. Lubricating oil is essential for machinery of all kinds and without it not a wheel would turn.

"Second. The potential supplies of crude oil outside of the United States are passing almost entirely into the political and economical control of foreign governments, and the United States is likely to pass from the position of dominance into a position of dependence.

"Third. Investigations of the Bureau of Mines, of the Fuel Administration, and of other bodies have disclosed that the known oil reserves of the United States are not receiving adequate protection, and are being wasted through inefficient methods in production, refining, and utilization of the oil."

The report says the Fuel Administration has made an investigation which shows that in 1917 in the exploitation of petroleum and natural gas in the United States the total waste in oil and gas amounted to $2,000,000,000, and continues:

"The need for petroleum reaches every citizen in the United States. The number of automobiles is increasing at the rate of 1,000,000 to 2,000,000 a year. Through pleasure cars, trucks, and farm

tractors, every family in the United States is virtually interested in gasoline.

"Through lubricating oils every person in the United States has a direct interest. Lubricating oils are one of the three essentials of modern civilization and in equal importance to steel and coal, for without lubricating oils no machinery would be possible.

"The supply of fuel oil is, in the opinion of marine engineers, the strategic point for our merchant marine and in the development of any modern navy."

The uncertainty of dependence upon new wells to supply the increased demand for oil is well illustrated by the compilation of the Boston News Bureau of January 27, 1920, viz.:

Well Production

Producing wells completed in the oil fields east of the Rocky Mountains in 1919 averaged 65 barrels daily output a well, initial flow. This compares with 90 barrels a well for 1918. Out of the 28,462 wells drilled in 1919, 5,951, or 21 per cent, were dry. North Louisiana wells, brought in in 1919, averaged 887 barrels daily production, North Texas 595, and Gulf Coast 432.5 barrels. Producing wells brought in in the Pennsylvania fields averaged the smallest of any division—10.5 barrels a well. Gulf Coast fields showed the largest number of dry holes, comparatively, as 561 out of 1,236 completions, or 45 per cent, were dry. Kentucky-Tennessee completions, numbering

3,716 for the year, showed only 421, or 11 per cent dry holes. The following shows the number of completions, dry holes, and initial daily output per well, in oil districts east of the Rockies during 1919:

	Completions	Dry holes		Average initial daily production of bbls. per well
		No.	%	
Pennsylvania	5,178	753	14	10.5
Lima-Indiana	834	159	19	21
Central Ohio	940	221	23	39
Kentucky-Tennessee	3,716	421	11	34
Illinois	370	112	30	44
Kansas	3,432	640	18	208
Oklahoma	8,196	2,266	27	93.5
North Texas	3,564	598	16	595
North Louisiana	704	123	17	887
Gulf Coast	1,236	561	45	432.5
Wyoming	303	87	28	275
Total	28,473	5,941	21	165

The average initial daily output of completions in the Pennsylvania fields, amounting to 10.5 barrels a well, is more than twice the average output of 4.5 barrels a well for the 225,000 producing wells in the United States. In the oil shale industry, the raw material for oil shale is absolutely certain and virtually inexhaustible, but the underground supply of petroleum is always an uncertain quantity and sooner or later is exhausted. For these reasons it is imperative that the United States take every step possible toward conserv-

ing its known reserves of oil. Petroleum and natural gas are not being replaced by nature and, once gone, cannot be replaced.

Many significant figures could be given, but a few will suffice.

	Total number of registered automobiles in the U. S.	Production of Gasoline in the U. S.
1914........	1,700,000	1,460,037,200 gallons
1918........	6,146,000	3,570,312,963 gallons

Increase in automobiles, 260 per cent; in production of gasoline, 145 per cent. It is predicted that 2,000,000 automobiles will be made in 1920.

Statistics furnished by the United States Geological Survey give the following interesting comparisons:

	Amount of Crude Oil in Storage	Amount of Crude Oil Marketed
Dec. 31, 1915	194,185,000 barrels	During 1915, 281,104,104 barrels
Dec. 31, 1916	179,371,000 barrels	During 1916, 300,767,158 barrels
Dec. 31, 1917	156,168,000 barrels	During 1917, 335,315,600 barrels
Dec. 31, 1918	132,800,000 barrels	During 1918, 345,896,000 barrels

Thus, during these four years the amount marketed increased from 281 to 345 million barrels; the reserve supply—that held in storage—decreased from 194 to 132 million barrels. From a production of 33 million barrels in 1891, the Pennsylvania fields have declined to 7,400,000 barrels in 1918. This gives the key to the oil situation. Oil pools are merely reservoirs certain to become exhausted in the course of a few years.

Examining the condition of the refining of oil we find that from January to September, 1918, the refineries consumed 182,000,000 barrels. During the same period the production was only 170,000,000 barrels. To meet this loss 12,000,000 barrels had to be drawn from storage, or more than a million barrels a month.

The enormous extent of the oil industry, the widespread demand for oil, and its influence upon industrial life may be seen from a glance at the following tables from the *Wall Street Journal:*

CRUDE OIL PRODUCTION AND CONSUMPTION IN THE UNITED STATES

Year	Consumption	Production	Excess of Consumption over Production
1912.....	225,000,000 barrels	224,000,000 barrels	1,000,000 barrels
1913.....	260,000,000 barrels	250,000,000 barrels	10,000,000 barrels
1914.....	280,000,000 barrels	264,000,000 barrels	16,000,000 barrels
1915.....	296,000,000 barrels	280,000,000 barrels	16,000,000 barrels
1916.....	320,000,000 barrels	300,000,000 barrels	20,000,000 barrels
1917.....	376,000,000 barrels	325,000,000 barrels	51,000,000 barrels
1918.....	396,000,000 barrels	340,000,000 barrels	56,000,000 barrels

The production for 1919 was 366,255,611 barrels, an increase of 26 millions over 1918, but the consumption has reached an estimated figure of 436,000,000 barrels or an excess of consumption over production of 70 million barrels, compared with an excess of 56 million barrels in 1918, 51 million in 1917, and only 20 million in 1916. The estimated production for 1920 is 400 million barrels and this is regarded as the peak of production.

IMPORTS FROM MEXICO

1912..........	1,000,000 bbl.
1913..........	10,000,000 bbl.
1914..........	16,000,000 bbl.
1915..........	16,000,000 bbl.
1916..........	20,000,000 bbl.
1917..........	28,000,000 bbl.
1918..........	41,000,000 bbl.
1919..........	60,000,000 bbl. (Estimated)

	U. S. Production by Fields		Estimated Available Oil in Ground (Nov., 1919)
	1917	1918	
Appalachian...........	24,932,000 bbl.	25,401,000 bbl.	550,000,000 bbl.
Lima-Indiana..........	3,670,000 bbl.	3,221,000 bbl.	40,000,000 bbl.
Illinois................	15,777,000 bbl.	13,366,000 bbl.	175,000,000 bbl.
Mid-Continent.........	163,506,000 bbl.	179,383,000 bbl.	1,725,000,000 bbl.
Gulf...................	24,343,000 bbl.	24,208,000 bbl.	750,000,000 bbl.
Rocky Mountain.......	9,199,000 bbl.	12,809,000 bbl.	
California.............	93,878,000 bbl.	97,532,000 bbl.	2,250,000,000 bbl.
Other Fields...........	10,300 bbl.	7,943 bbl.	[1]1,250,000,000 bbl.

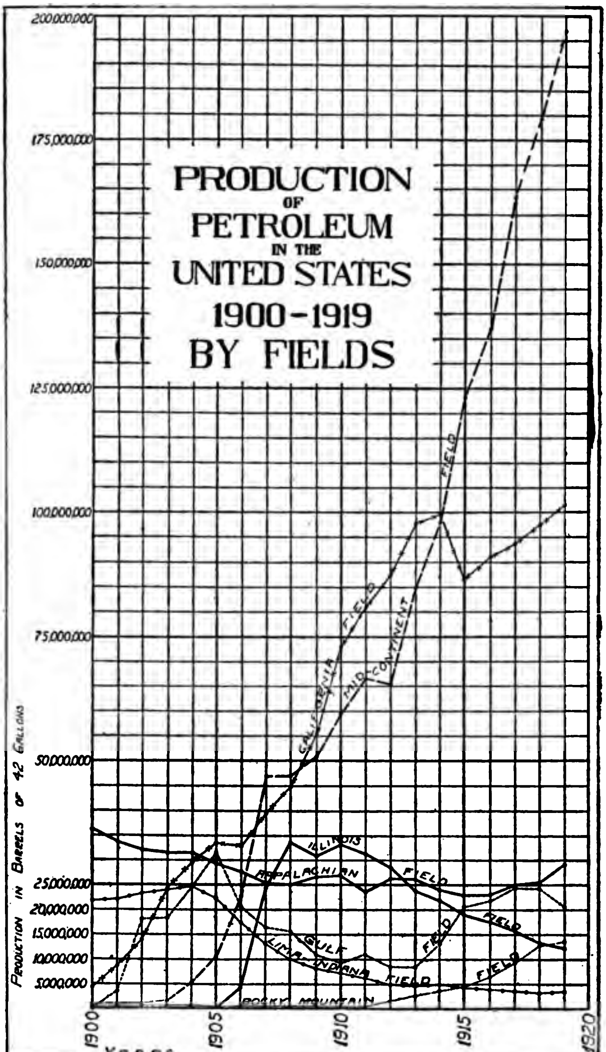
[1] Including Wyoming and Rocky Mountain.

PRODUCTION BY PRODUCTS IN 1918

Gasoline........	85,000,000 bbl.
Kerosene.......	43,400,000 bbl.
Gas and Fuel Oil	174,300,000 bbl.
Lubricants......	20,000,000 bbl.
Wax...........	1,900,000 bbl.
Coke...........	3,600,000 bbl.
Asphalt........	33,500,000 bbl.
Other products..	30,600,000 bbl.
Total......	392,300,000 bbl.

Status of the Oil Producing Fields

The Appalachian field is the oldest in the United States. Oil was first found by Col. Drake at Titusville, Pennsylvania, in 1859. Until 1885 Pennsylvania produced virtually the entire output of the country or 98.50 per cent. The maximum output occurred in


PRODUCTION OF PETROLEUM IN THE UNITED STATES 1900-1919 BY FIELDS
200,000,000
175,000,000
150,000,000
125,000,000
100,000,000
75,000,000
50,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
PRODUCTION IN BARRELS OF 42 GALLONS
1900
1905
1910
1915
1920
YEARS
CALIFORNIA FIELD
MID-CONTINENT FIELD
ILLINOIS
APPALACHIAN FIELD
GULF FIELD
LIMA-INDIANA FIELD
ROCKY MOUNTAIN FIELD

1900—36 million barrels. Since that time the output has decreased to 25,401,000 barrels in 1918.

The Lima-Indiana field has been a producer since 1884. The output was greatest in 1904, 24,689,184 barrels. This has decreased to 3,211,000 barrels in 1918.

The Illinois field became a producer in 1905. The maximum production was reached in 1908—33,686,000 barrels. This has declined to 13,366,000 barrels in 1918.

The Mid-Continent field became an important producer in 1904 and has increased its output steadily to 179,383,000 barrels in 1918. It is estimated, however, that for 1919 the production has dropped to 115,000,000 barrels.

The North Texas field became important in 1911. The production in 1918 was 17,280,612 barrels; this has been increased to 67,419,000 barrels in 1919.

The Gulf field became important in 1901. The maximum output was reached in 1905—36,526,323 barrels; this fell to 24,208,000 in 1918.

The Rocky Mountain field, before 1912, produced less than one million barrels a year, but this amount has increased to 12,809,000 barrels in 1918; the peak of production has not yet been reached.

In the California field the maximum production was reached in 1914—100,000,000 barrels; in 1918 it fell to 97,532,000 barrels.

To generalize: the Appalachian, Lima-Indiana,

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and Illinois fields have passed their peak of production; the Gulf, California and Mid-Continent have just about reached their peak; North Louisiana, North Texas, and the Rocky Mountain fields have not reached their peak and largely increased production may be expected.

The advance in the price of crude oil is likewise suggestive:

	Current Price July, 1920	Low Price in 1915
Pennsylvania	$6.10	$1.35
Corning	4.00	.83
Cabell	3.92	.97
Somerset	3.75	.80
Ragland	1.75	.63
North Lima	3.73	.93
South Lima	3.73	.88
Princeton	3.77	.89
Indiana	3.63	.83
Illinois	3.77	.89
Kansas-Oklahoma	3.50	.40
Healdton	2.75	.30
Caddo, heavy	2.00	.35
Canada	4.13	1.28

Fuel oil is variously quoted, according to the section of the country in which it is sold, but in general it may be said that current prices are from 30 to 50 per cent above those of January 1, 1919, and from 100 to 300 per cent and more above the lows of 1914. Refined products as yet have not displayed the same strong tendency to advance as noted in crude, but that is natural in view of the

fact that the refined output is being forced to capacity in every plant. Practically all refined products are at the highest price levels in their history, with an extremely firm undertone. There is likely to be a sudden and sharp increase in prices for all refined products, according to the best opinion, for the greatest demand ever known is in prospect. Inasmuch as high prices result in more active drilling operation, oil companies are preparing to make 1920 a year of banner production, so that the peak of well petroleum will very likely be reached, but thereafter a steady decline will probably ensue.

Besides the common uses of petroleum, known to every one, the following new uses will form increased demands:

New Uses for Petroleum

1. Airplanes. Since the close of the war and the abandonment of the airplane for war work, industrial uses are open for it. Already aerial mail service is in force; next will be light express service, and then passenger service. Soon the planes will be almost as common in the air as birds and rapid transportation will be revolutionized.

2. Motor trucks. Between the large centers of population and the surrounding towns, as well as from the smaller distributing centers, the auto truck has begun to displace railroad freight service in the branch and short haul. The four handlings of the freight service is reduced to two. To this is the added advantage of frequent direct service.

In 1904 only 411 motor trucks of a total wholesale value of $946,947 were manufactured. In 1919, 305,142 motor trucks were manufactured, of a total value of $408,311,585.

3. Tractors. Tractors for farm use form the next step in farm improvement. Their advantage is very great and their increased use unquestioned.

4. Oil burning steamers. The use of petroleum as fuel in steamers is rapidly increasing. A ton of oil occupies five cubic feet less space than a ton of coal and gives eighty per cent steaming efficiency as compared with sixty-five per cent for coal. The increased cargo room available, when oil is used, with the certainty of enhanced financial returns from freight, makes the use of oil on all classes of steamers in the near future a foregone conclusion.

5. Oil for road use. The cheaper grade of oil and residues form an excellent material for road-making. Its use in California is an object lesson to every automobilist in that State.

In passing judgment upon the condition of the oil industry as a whole, one must not be blinded by the enormous production of gushers, nor be made unduly pessimistic over the low average yield of the quarter of a million wells in the United States. A common sense view seems to be that first, our supply of petroleum from wells is not meeting the country-wide demand and that the limit of production is approaching; second, the supply of petroleum from wells can be maintained

only by the discovery of new extensive pools; third, there is little likelihood that new pools like the Mid-Continental, or California, will be discovered because the entire country has already been explored; fourth, that the only great national reservoir that can be absolutely depended upon to supply oil is our enormous deposits of shale. This will undoubtedly be the source of our oil supply for the future. In the words of George Otis Smith, Director of the United States Geological Survey, the oil situation in the United States is "precarious."

CHAPTER II

NATURE, ORIGIN, AND DISTRIBUTION OF OIL SHALE

Oil shale virtually contains no oil as such. It is a consolidated mud or clay deposit from which petroleum is obtained by distillation.

Nature

In appearance, the shale is black, or brownish-black, but on weathered surfaces it is white or gray. It is usually fine grained, with some lime and occasionally sand. It is tough but, in thin sections, friable. When broken to a fresh surface it may give an odor like petroleum. Thin rich pieces burn with a sooty flame. E. H. Cunningham-Craig defines it as follows: Oil shale is an argillaceous or shaly deposit from which petroleum may be obtained by distillation but not by trituration or treatment by solvents. Oil shale must be carefully distinguished from oil sand. In the oil sand, the oil is contained in the sand as oil. When the sand is penetrated by a well the oil gushes out or is pumped out. In the oil shale there is no oil as such, but only the uncooked ingredients of oil. When the shale is subjected to destructive distillation, i. e., heated in a closed

vessel, or cooked, shale oil results as a manufactured product.

Oil shale may also be regarded as an unfinished oil field and is one of a long list of natural deposits which resulted from the decomposition of organic matter from plants or animals of a former geologic era—like anthracite, bituminous, and brown coal; peat, petroleum, and asphaltum. Beds of oil shale were laid down in lakes, lagoons, or wide expanses of quiet water. They contain a large amount of organic matter—low plant forms of life like algæ; also pollen, fish scales, insects, and remains of animal and vegetable life sometimes changed beyond recognition, although 277 species of insects have been recognized.

Origin

Oil shale is found in Colorado, Kentucky, Utah, Wyoming, Texas, Pennsylvania, Nevada, Montana, West Virginia, and California. In Canada it is found in Quebec, New Brunswick, Nova Scotia, and Newfoundland. In Scotland, near Edinburgh and on the Isle of Skye. In France, at Autun, Buxiere les Mines and in the Riviera. In South Africa, in the Transvaal, Mozambique, and Natal. Also in New South Wales, New Zealand, Tasmania, Brazil, Italy, Spain, Austria-Hungary, Serbia, and Turkey. In England it occurs in Norfolk.

World-wide Distribution

The oil shale beds of Scotland occur within a small area, twenty miles in diameter, in the counties of West Lothian, Mid Lothian, and Lanark-

shire. The center of the district is fourteen miles west of Edinburgh. The shale beds are simply a very fine impalpable clay shale, brown to black in color, free from silica, easily cut with a sharp knife, and in form are plain or curly. The beds vary greatly in thickness; it is not uncommon to find a seam pinch out altogether, but another seam, above or below it, increases in thickness and richness as the first deteriorates. Faults, folds, and igneous intrusions are not uncommon. Mining is done entirely through shafts. "Kerogen" is the Scotch term given to the complex organic compounds in the shale which produce petroleum. The richer shales yield from 30 to 40 gallons of oil to the ton of shale. The lower grade shale that yields only from 15 to 18 gallons gives from 60 to 70 pounds of ammonium sulphate. That is, the shale that runs high in oil runs low in ammonium sulphate; the shale that is low in oil is high in ammonium sulphate. In the earlier days of the industry the shales that were worked produced more crude oil than the shales of to-day. Notably the Torbane Hill material gave from 96 to 130 gallons of crude oil a ton. At the present time the production seldom exceeds 30 gallons a ton, and shale yielding only 15 gallons is successfully treated. The explanation of this lies in the fact that crude oil is not the only product of value that may be obtained. The ammonium sulphate is also valuable. If this is obtained in large quantity, as in the case of

Scotland

shale now being treated, the total result in crude oil, plus ammonium sulphate, may be economically profitable. The following series of products are secured from the Scotch shales:

1. Permanent gases used for fuel under retorts.
2. Naphtha, gasoline, and motor spirits.
3. Burning or lamp oil.
4. Intermediate oil used for gas-making.
5. Lubricating oil.
6. Solid paraffin.
7. Still grease.
8. Still coke, which contains some oil and is used for gas, smokeless fuel, and carbon for electrical purposes.
9. Ammonium sulphate.
10. Liquid fuel used in the refineries.

The Scottish seams of oil shale that have been worked, at various times, have given approximately the results shown in table on page 19.

The present output of shale is approximately 3,500,000 tons annually, valued at $15,000,000.00. In the various parts of the industry 12,500 men are now employed.

The refineries are now producing from the oil shale approximately:

Burning oils	20,000,000	gallons
Naphtha	5,000,000	gallons
Lubricating oils	22,000,000	gallons
Paraffin wax	25,000	tons
Sulphate of ammonia	54,000	tons

Name	Thickness	Gal. of Crude Oil, Long Tons	Ammonium Sulphate lb., Long Tons
Torbane Hill		96–130	
Levenseat	11 in.	29	
Raeburn	3–6 ft.	40–55	14
Addiewell	20 in.	28	13–18
(Not much worked)			
Fells	3–5 ft.	26–40	20–35
(The principal shale of the West Calder District. Extensively worked)			
OAKBANK SHALE—			
Wee	1½ ft.	36	
Big	4 ft. 6 in.	22	
Wild	6 ft.	29½	34–41
Curly	6 ft.	22	35
Lower Wild	5 ft. 6 in.	19	
New	8 ft. 6 in.	21	
Dunnet	4–12 ft.	24–33	14–34
(Extensively worked)			
Barracks	8 ft.	18–22	
BROXBURN SHALE—			
Broxburn gray	6 ft.	20–33	34–41
Broxburn curly	5 ft. 6 in.	19–33	11–38
Broxburn seam	5–6 ft.	10–51	7–40
PUMPHERSTON SEAMS—			
Jubilee	8 ft.	18	55
Maybrick	5 ft.	16	60
Curly	6 ft.	20	52–67
Plain	7 ft.	20	60
Wee	4 ft.	18	60
Mungle	2 ft.	35	30
(Not much worked)			

D. R. Steuart in "Economic Geology," Vol. 3, 1908, p. 574, describes briefly the equipment as follows: "In a Scotch oil works there are the great benches of shale retorts sometimes more than 60 feet high, with the great stacks of numerous series of 3-inch pipes, 30 to 40 feet high, for air condensers. There is the three-story-high sulphate of ammonia house, with its high column-stills, the acid saturators for the ammonia, vacuum or other evaporator for the sulphate from the recovered sulphuric acid of the refinery, centrifugal driers, storage and grinding mills. In the refining departments the stills are small and, on account of the repeated distillations, very numerous; the washers for vitriol and soda are many; there are coolers, refrigerators, filter and hydraulic plate presses for the separation of the heavy oil and solid paraffin; great sweating houses for the paraffin refining; candle works; sulphuric acid plants; acid recovery plant; engineer's, joiner's, and plumber's shops—a very large and varied collection of apparatus covering much ground, so that for a comparatively small production there is a very large and expensive plant. A conspicuous feature of the works is the great hills of spent shale."

Description of the Scotch Oil Works

In 1913 oil shale was discovered on the Isle of Skye. It is fine grained, brown in color, fossiliferous, tough, and resists disintegration by weathering. At the outcrops it is from seven to ten feet in thickness. Two samples from the outcrops gave:

Isle of Skye

	Crude oil gallons a ton	Ammonium sulphate, Pounds a ton
1.	12	6.2
2.	12.8	7.4

It is not now of commercial importance.

England

The oil shale deposits of England cover an area of one hundred square miles in Norfolk, a few miles from the port of King's Lynn on The Wash. It is entirely controlled by the English Oilfields, Ltd., capital $1,500,000. Enough test holes have been sunk to determine accurately the depth, character, and extent of the oil shale seams. Holes to a depth of 300 feet show seams of shale aggregating 150 feet. The thinnest is four feet in thickness. The seam which is now being mined at West Winch is 14 feet thick. These deposits, virtually flat, are noteworthy for regularity of strata, thickness of the beds, uniformity of dip, and persistence of oil value. The seams do not vary in dip more than two or three inches in a distance of ten or twenty miles. The whole formation must have been laid down over a wide lake area and the deposition must have been very slow and regular. The limits of the deposit have been accurately defined by borings. It is safe to say that the English Oilfields, Ltd.—the controlling company—has title to the entire deposit. Complete equipment is installed for mining and retort-

ing 1,000 tons of shale a day. A daily production of 45,000 gallons of oil and 70,000 pounds of ammonium sulphate is expected. The retorts are especially designed, after repeated experiments, for the shale to be treated, and are distinctly different from the Scotch type. The shale gives from 50 to 60 gallons of shale oil to the ton. A refining plant treats the crude shale oil as it comes directly from the distilling plant, so that the mining, retorting, and refining are virtually conducted in one general plant. The oil resulting from the Norfolk shale is distinctly different from the Scotch oil. The Norfolk crude is of a light nature, produces a long range of lubricants, 60 to 70 pounds of ammonium sulphate to the ton, and 15 per cent of paraffin wax. The discovery and commercial development of this Norfolk oil shale deposit, in the opinion of English experts, is not only of national importance, but marks an era in the industrial history of England comparable with the discovery and development of her coal deposits.

Canada

As far as our present knowledge extends it is evident that Canada is not so well supplied with oil fields as the United States. For this reason the oil shale industry is likely to make rapid advancement within the Dominion. The Geological Survey and the Bureau of Mines have already given considerable attention, in examinations and reports, to these

deposits, especially to the vast deposits known to exist in the Peace River territory in northern Saskatchewan.

New Brunswick

The oil shales of New Brunswick are located chiefly in three areas—the Taylorville, Albert Mines, and Baltimore. In Taylorville are four beds of shale of good quality; one five feet, one three feet, and two, one foot ten inches thick. In Albert Mines are six beds of the following thickness (the most important in New Brunswick): 6.5 feet, 3.5 feet, 5 feet, 4.5 feet, 6 feet, and one with thin beds of oil shale. In Baltimore are four beds, 4 feet, 5 feet, 7 feet, and 6 feet thick, respectively. The shale beds of Canada—especially in New Brunswick—are proving on careful examination to be richer and more extensive than was first supposed and, when fully developed, are likely to be a source of great wealth. They are generally accessible and easily worked.

Results of analysis of New Brunswick oil shales made by the Mines Branch of the Canadian Geological Survey is shown on page 24.

Other shale deposits in New Brunswick are the Prosser Brook, the Pleasant Vale, the Mapleton, the Elgin, Goshen, Sussex, and Norton shales. Thirty-six tons of New Brunswick shale tested at the Pumpherston Oil Co., Scotland, gave an average of 40.09 gallons of crude oil and 76.94 pounds of ammonium sulphate a ton. The New

Brunswick Shale Co., Ltd., capitalized at $5,000,-000, has been organized recently to develop the New Brunswick deposits.

	Crude oil, Imperial gal., a ton	Specific gravity of the oil	Ammonium sulphate—pounds a ton
ALBERT MINES—			
Bed No. 1—6.5 feet thick.....	48.5	0.892	82.8
Bed No. 2—3.5 " "	38.8	0.892	60.3
Bed No. 3—5 " "	45.5	0.891	48.
Bed No. 4—4.5 " "	43.5	0.896	56.8
Bed No. 6—6 " "	27.0	0.895	49.1
DOVER SHALES—			
Average of four samples.......	27.2	0.921	29.5
TAYLORVILLE SHALES—			
Adams Farm, Taylorville......	43.0	0.900	93.0
Taylor " " No. 1	48.0	0.910	98.0
" " " No. 2	37.0	0.925	110.0
Adams " " No. 1	42.3	0.897	96.5
" " " No. 2	47.3	0.901	88.7
Taylor " " No. 1	46.8	0.902	85.0
" " " No. 2	45.0	0.903	101.0
BALTIMORE SHALES—			
Baizly......................	54.0	0.895	110.0
E. Stevens..................	49.0	0.892	67.0
Geo. Irving.................	40.0	0.895	77.0
West Branch (gray shale)......	56.8	0.891	30.5

Nova Scotia

Oil shales were first discovered in Pictou County in 1859. They are also found in Antigonish County. Analysis of Pictou County shale gave two satisfactory results:

	Crude oil, Imperial gal., a ton	Specific gravity of a ton	Ammonium sulphate—pounds a ton
Bed No. 1	42.0	0.889	35.0
Bed No. 2	14.5	0.892	41.0
Analysis of Antigonish County shales gave:			
Bed No. 1	11.0	0.917	22.6
Bed No. 2	10.0	0.893	38.0
Bed No. 3	23.0	0.906	34.0

The oil bearing shales of Quebec are found in the Gaspé Basin. The outcrops are from 12 to 15 inches in thickness. Samples tested by the Canadian Bureau of Mines resulted as follows:

Quebec

	Crude oil, Imperial gal., a ton	Specific gravity of the oil	Ammonium sulphate—pounds a ton
Bed No. 1	30.0	0.962	42.20
Bed No. 2	31.5	0.977	40.00
Bed No. 3	36.0	0.953	59.50

On account of the thinness of these beds their economic value is doubtful.

The oil shales of Newfoundland cover an area of about 750 square miles. The largest deposit lies between the head of White bay and Deer and Grand lakes, and varies from 50 to 100 feet in thickness. The dip of the strata is slight and the outcroppings are bold. An

Newfoundland

analysis of typical shale gave 50 gallons of crude oil and 80 pounds of ammonium sulphate a ton. The Newfoundland shales have great prospective value.

France

Second only to the oil shale industry in Scotland ranks the French, which dates from 1830. After many years of successful operation it suffered from competition with oil wells until the French Government in 1890 offered a premium for the production of oil from shale. This bonus, together with the adoption of efficient Scotch methods of treatment, revived the industry. The shales occur at depths from 150 to 300 feet. Five companies are now in operation on the shale of Autun and Buxiere les Mines, where the shale produces 50 gallons of oil a ton. The best oil shales of France, however, are in southern France in the Riviera, especially the deposit of the Mines de Boson, five miles north of Frejus, in Var, owned by Mines de l'Estrel. The seam is five feet thick, dips at an angle of 30 to 40 degrees, and yields from 80 to 120 gallons of oil to the ton. The oil is free from sulphur, of .86 gravity, and, when refined, gives 18 per cent gasoline and 25 per cent of lubricants. The property is equipped with a retorting plant and a cracking plant of the Hall (English) type. This is the only French oil shale deposit to be developed in recent years, but the scarcity and high price of coal, as well as the demand for petroleum products, makes it probable

that other oil shale deposits known to exist in southern France will be developed in the near future.

Large outcrops of rich oil shales occur in the gorges of the Blue mountains, New South Wales. Fossils are found in the lower shale measures. These shales are reported to give 100 gallons of oil and 70 pounds of ammonium sulphate a ton. The government has established a system of bonuses, for the production of oil, which are expected to increase the present annual production from 3,000,000 to more than 20,000,000 gallons. There are two British-Australian companies in the field—the Commonwealth Oil Corporation, capital $6,000,000, operating at Newnes, and the British-Australian Oil Co., capital $1,460,000, operating at Temi in the Liverpool range. From 1865 to 1916, 1,751,367 tons of oil shale have been produced of a total value of $11,606,671.

Australia

Oil shale is found in two districts—the Ermelo and the Wakkerstroom, fifty miles apart. Although these two deposits may prove to be one continuous bed, there is no evidence to that effect at the present time. In each case the shale is associated with a seam of coal. The Ermelo shales have produced from 30 to 34 gallons of crude oil to the ton. The Wakkerstroom shale has yielded as much as 90 gallons a ton, but the shale is only 9 inches thick.

Transvaal

Oil shales are exposed at many places on the coast of Brazil. They have been examined by Professor John C. Branner, of Leland Stanford, Jr., University, and their composition determined by the late Sir Boverton Redwood, of London. The richest yielded 44.73 gallons of crude oil and 19.58 gallons of ammoniacal water to the ton. The deposits have not been worked commercially.

Brazil

A Governmental commission has recently reported upon the oil shale resources of Sweden and the domestic needs for oils. It is estimated that the country's needs are annually:

Sweden

Lamp oils....	100,000,000 kilos.
Lubricating oil	25,000,000 kilos.
Petroleum ...	13,000,000 kilos.
Other oils	20,000,000 kilos.

The oil shale resources are estimated at 5,260,000,000 tons, found at Kinnekulle, Narke, Osergotland, and Oland. From tests made upon the shale oil it is calculated that the following products can be obtained:

Fuel oils....................	25.5 per cent
Lubricating oils............	34.5 per cent
Asphaltum and tar.........	18.5 per cent
Ammonium sulphate...	7 to 9.5 per cent

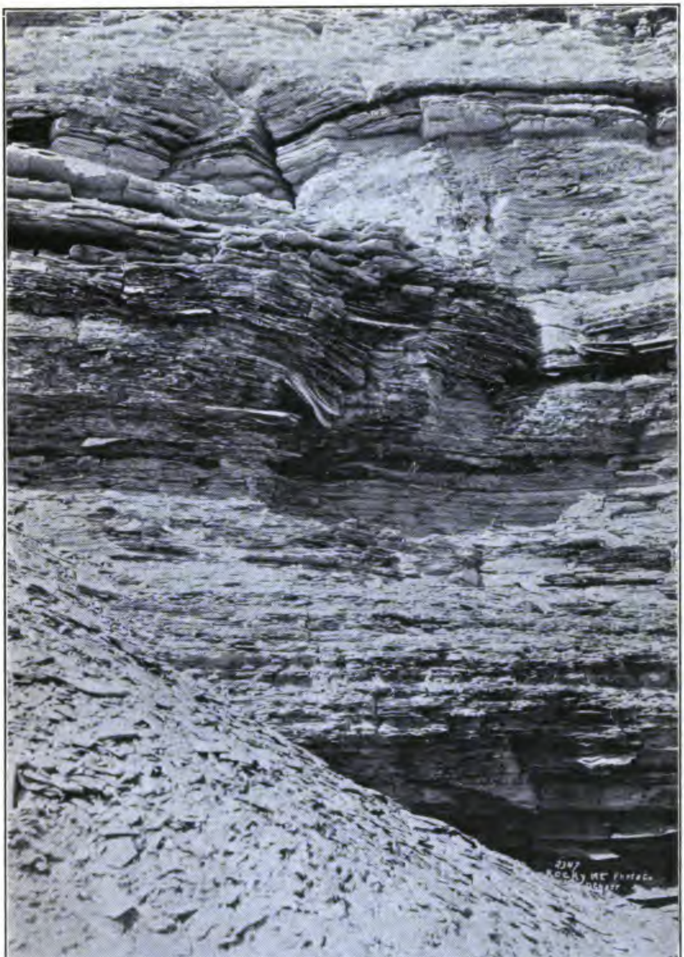
The Uintah Basin

At the end of Cretaceous and the beginning of Tertiary times, there occurred in the Rocky Mountain region earth movements which resulted in a great inland basin or lake, covering a distance of three hundred miles north and south and two hundred miles east and west, over what is now northwestern Colorado, northeastern Utah, and southwestern Wyoming. It is a topographic as well as a structural basin, limited by the Uintah mountain uplift on the north, by the Roan cliffs on the south, by the Wasatch mountains on the west, and by the Rangely dome on the east. The oil shales lie in the Green River formation; they are covered by newer formations in the northern portions, but are well exposed in the south. They can be explored and studied over an area of 40 by 125 miles. This deposit is undoubtedly the most extensive, the richest, and the most accessible in the world. As a reserve for the use of the Navy, the United States Government has withdrawn from this area in Colorado 45,440 acres and in Utah 86,584 acres. In the Utah portion of the Uintah basin alone there are available more than 40,000,000,000 tons of oil shale that will yield more than a barrel of oil to the ton. If 100 plants were to work continuously 365 days in the year, each treating 2,000 tons a day, it would require 550 years to exhaust this supply.

In Colorado the oil shale occurs chiefly in Garfield, Rio Blanco, and Moffat counties, and covers

Colorado

2,500 square miles. The towns of Grand Valley and De Beque, on the line of the Denver and Rio Grande Railroad, are the points of entrance. The exposed shales of the De Beque district lie northeast, north and northwest of the town, on both banks of Roan creek, on its largest tributaries, Conn, Kimball, and Dry Fork creeks, and on all of its smaller tributaries. Within a radius of 30 miles from De Beque there are 175 miles of continuous outcroppings of ore shale. A measure of the interest and activity in the oil shale industry can be realized from the fact that since June, 1916, there have been more than 1,500 filings on oil shale land in Garfield County. In the Parachute region of the Grand Valley district is a well defined rich oil shale stratum—twelve to twenty feet thick—that is exposed on both banks of Parachute creek and all its side streams continuously for a total distance of sixty-nine miles. Many tests show that it will yield an average of at least forty-two gallons, or one barrel of oil, to the ton. Assuming that this stratum extends only a mile and a quarter back from the line of exposure—a conservative estimate—the area of this stratum is at least 55,000 acres. This estimate does not include the shale exposed on Battlement Mesa east and southeast of Grand Valley. Using the minimum thickness of twelve feet, allowing 25 per cent of the volume to be left as pillars, and counting only on forty-two gallons to the ton, this stratum alone would contain 1,012,500,000 barrels



PAPER SHALE.   COLORADO   30

MASSIVE SHALE. UTAH

of crude oil. To one fond of figuring the following will prove interesting. An acre contains 43,560 square feet. A seam of oil shale 10 feet thick would contain 435,600 square feet. Eighteen cubic feet of shale weigh one ton. Hence there are 24,200 tons of shale in one acre of a seam 10 feet thick. In a square mile there are 640 acres and therefore 15,488,000 tons of shale. There are 2,500 square miles of shale in Colorado, or 38,720,000,000 tons. Assume that only one-half is available and there remains 19,360,000,000 tons of available shale. This is figured for one ten-foot seam only. A conservative estimate is 30 feet of workable shale or a total of 58,080,000,000 tons of available shale. A fair average production is a barrel of oil to the ton of shale or 58,080,000,000 barrels of oil available. If 100 plants were in operation, each treating 2,000 tons daily, they would have a daily production of 200,000 barrels. To treat this amount of shale would require 290,400 days or 800 years, approximately. These figures apply only to Colorado; they omit shale deposits elsewhere, and are given only to make vivid and emphatic the oft-repeated statement that "there are mountains of oil shale."

Nevada

The most important deposits in Nevada are at Elko, and extend over a belt 30 miles in extent. Two experimental plants are now in operation; the plant of the Southern Pacific Company under the supervision of the United States Bureau of Mines—a Pumpherston

(Scotch) retort—and the plant of the Catlin Shale Products Company. The shale at the Catlin plant produces fifty gallons of oil to the ton with a paraffin base. At Carlin the oil shale occurs in the form of vertical dikes up to 300 feet in width, and has an asphaltum base.

Montana

The oil shales of Montana, near Dillon, offer a new problem to the experimenter. They are peculiar in that they contain phosphoric acid and the beds are called phosphoric oil shale. It was hoped that both oil and phosphate could be obtained in profitable quantities, but field work and investigations of the United States Geological Survey have shown that this result is not possible at the present time. In the Dillon region the ~~ore~~ oil content of the phosphoric oil shale, where the richest shale beds are only three feet, does not exceed 30 gallons to the ton. The phosphate beds also are thin and contain but a small amount of phosphorus pentoxide. In Southwestern Idaho the shale associated with high grade phosphate rock yields little or no oil. It seems, therefore, that at the present time these beds would not be commercially profitable.

CHAPTER III

THE HISTORY OF THE OIL SHALE INDUSTRY

Early Investigation

In the course of his classical investigations on the tar produced in the dry distillation of wood, Reichenbach, in 1830, discovered in it, among other things, a colorless, wax-like solid which he called paraffin because he found it to be endowed with an extraordinary indifference towards all reagents. A few years later he isolated from the same material a liquid oil chemically similar to paraffin, which he called eupion (very fat). For many years both these bodies were known only as chemical curiosities. This was natural enough as far as paraffin was concerned, but it is rather singular that it took so long before it was realized that eupion, or something very much like it, forms the body of petroleum which had been known, ever since the time of Herodotus at least, to well up abundantly from the earth in certain places. Though extensively known, it was used only as an external medicinal agent, until James Young conceived the idea of working a comparatively scanty oil spring in Derbyshire, and subsequently found that an oil similar to petroleum is obtained by the dry distil-

lation of cannel coal and similar materials at low temperatures.

Scotland

The shale oil industry is not new. It has been successfully developed and operated in Scotland for nearly seventy years. The first material to be subjected to dry distillation, which furnished the earliest known distillation tar, was described by Boyle in 1661. About this time tar was recovered from the dry distillation of pine in Norway and Sweden. In 1661 a patent was taken out by Becker in England for the recovery of tar and pitch from coal. Becker was also the first to produce coke. The one outstanding achievement, however, in the shale oil industry is due to James Young. The possibility of extracting oil from bituminous shale had long been known in Scotland, but the small plants which had been erected were of brief existence and of little importance. At the suggestion of Lyon Playfair, Young built a refinery for treating petroleum obtained from a spring at Alfreton, in Derbyshire. He produced two kinds of oil, one for lubricating and the other for burning in lamps. Paraffin was also obtained but not utilized to any extent. Within two years the supply began to fail and in 1851 the business ceased. Meanwhile, it had occurred to Young that the oil had been produced by the action of heat upon coal, so he attempted to produce an artificial oil by this means. As a result of a long-continued investigation with many varieties of coal he secured a patent in October,

1850, which became the basis of a new industry. "The coals," the patentee says, "which I deem to be best fitted for the purpose are such as are usually called parrot coal, cannel coal, and gas coal, and which are much used in the manufacture of gas for the purpose of illumination." Early in 1850 a material called Boghead coal from Torbane Hill was brought to his attention. This he found to be the most promising of any material he had investigated. In 1850, a plant was erected at Bathgate. The salient feature of Young's invention was the distillation of bituminous substances at the lowest possible temperature for the production of volatile compounds. In practice it was found that the best results were obtained at about 800°F.

In the early days of the industry in Scotland, Boghead coal or Torbane Hill mineral, as it is sometimes called, was the only material distilled. As the same material was used for the production of illuminating gas, it rose rapidly in price and in 1866 disappeared. When the supply of Boghead coal ceased, another material, well adapted for distillation, was found in the oil shales existing in the Scottish carboniferous formation. In 1859, a seam was experimentally opened at Broxburn and by 1864 several plants were in operation. But although the Boghead coal produced 120 to 130 gallons of oil a ton, the shales yielded only about 35 gallons and at the present time produce even less. In 1850, a plant was erected at Bathgate. In 1861, a second, the Crofthead Oil Works, was in

operation. In 1857, when Young's patent expired, thirty-eight new works were established. In 1860 there were six; in 1870, ninety; in 1880, twenty-six; in 1890, fourteen; in 1900, nine. At the present time four companies are operating: Young's Paraffin, Light and Mineral Co., Ltd.; the Oakbank Oil Co., Ltd.; the Broxburn Oil Co., Ltd., and the Pumpherston Oil Co., Ltd. There are three other companies which produce only oil and ammonium sulphate.

At the beginning of the industry in Scotland, horizontal retorts were used, but were soon supplanted by the vertical type. In form the horizontal retorts were of oval, or rectangular, shape made of cast iron; at one end was a door and at the other a pipe for the removal of vapor to the condenser plant. The material was charged and discharged through the door, so that the operation of the retort was intermittent. To secure a continuously working retort, the vertical type was introduced. These were narrow, oval, or circular cast iron pipes, surrounded by brickwork. They were charged from a hopper at the top and discharged at the bottom through a trough filled with water which acted as a seal. The vapors escaped through the pipe on the side of the retort near the top. Coal was used as fuel. These retorts had the advantage over the horizontal retorts of continuous working and a greater yield of oil. Their life was, however, short—six to nine months—on account of corrosion. In these early retorts, de-

composition was effected at the expense of the paraffin content with the result of an oil low in paraffin. To produce an oil which would be rich in paraffin, Young conducted exhaustive experiments which resulted in the late sixties in a retort of increased diameter. In this type the retort was jacketed and the vapors were taken off at the bottom. To effect a more economical working and to obtain a lower distillation temperature, Young later began to use the spent shale instead of coal as a source of heat. A retort was devised by which he proved that the spent shale could furnish enough heat for distillation, but it was too delicate for operation by workmen with hundreds of retorts to look after. In 1873, a retort was constructed by N. M. Henderson. A set of these retorts was installed in the Oakbank works in 1874 and did good work for twelve years, when they were replaced by an improved type. They were also used at Broxburn and contributed greatly to the success of the Broxburn Oil Co. The retorts of Young and Henderson, in which shale was burnt, were able to work at a lower distillation temperature and the oil produced was of better quality and richer in paraffin. The working costs were also reduced considerably. Until 1880, the yield of oil was thought to be the most important feature in the process of distillation, and the recovery of ammonia a side issue. At this time Young and Beilby began to investigate the possibility of increasing the yield of ammonia.

A retort was constructed with an upper section of cast iron in which the shale was acted upon by a gentle heat for the production of oil, and a lower section of fire brick where the temperature was higher and where steam was introduced. From this retort an excellent oil was produced and the yield of ammonia and gas was increased. The disadvantages were that it required very close attention and its liability to choke if the temperatures became so high as to fuse the charge in the lower portion. To avoid these difficulties, Young constructed a retort known as the Pentland; the diameter was increased, the upper section constructed of iron, and the lower of fire brick. The joint between the two was very carefully made. The retort was 27.5 feet high. The temperature in the upper zone was maintained at about 750°F. (400°C.) and in the lower zone, 1300°F. (700°C.). The shale was kept in continuous motion by a toothed roller at the bottom of the retort. This prevented caking and the obstruction of the retort. The roller also discharged the spent shale into an iron box from which it was run into cars. The retort was easy to operate and required little attention. Fresh shale entered the retort in proportion as spent shale was discharged. The yield of ammonia was greater than that from other retorts and the oil was of a good grade.

The earliest record of oil shale investigation in America is that of Dr. Abram Gasner, who, in 1815, erected a small retort at Baltimore, New

UTAH OIL SHALE

A MOUNTAIN OF OIL SHALE. COLORADO

Brunswick, to treat the albertite shale of New Brunswick. In Boston, the Downer Oil Company from 1854 to 1861 treated albertite from New Brunswick and manufactured lamp oil and paraffin. About 1855 the Mormons distilled oil from shale. The ruins of an oil retort still remains at Juab, Utah, as evidence of their early knowledge of the character of the oil shale of that region. Between the years 1850 and 1860 more than fifty plants were erected in the eastern states and along the Atlantic Coast to retort imported Boghead coal, by Young's process, and also local coals and shales. Plants were also erected to treat the Albert Mines shale in Canada. When, however, in 1859 oil was produced from wells in abundant quantity, the distillation plants were compelled to close, but were later remodeled as refineries of well petroleum. D. R. Steuart says, in "Shale Oil Industry in Scotland," "James Young may claim to be the father, not only of the Scotch shale oil industry, but also the great American petroleum industry." The supply of well oil was so abundant and so cheap that the production of oil from shale became unnecessary. Nothing was, therefore, done for many years.

United States

In 1910 Ralph Arnold and C. A. Fisher examined the shale deposits of Parachute creek, Grand Valley, Colorado, and called attention to the richness and extent of these deposits. In 1911 and 1912 Joseph Bellis and James Doyle became interested

and were among the first to locate claims under the placer law. In 1913, the United States Geological Survey, believing that at some future time the deposits of oil shale would be needed to furnish a supply of oil, and realizing the necessity of providing authentic information on the subject, placed a party in the field to investigate the oil shale deposits of northwestern Colorado, northeastern Utah, and southwestern Wyoming. The work has been almost continuous since that time, ~~either~~ in the field or in the laboratory, and has been done chiefly by E. G. Woodruff, Dean E. Winchester, D. Dale Condit, and David T. Day. The results have been published in Bulletins of the Survey and have been invaluable to all who have been interested in the subject.

Development of the Industry in the United States

The action of the Survey in examining and calling public attention to these oil shale deposits attracted the attention of chemists, engineers, oil men, and technicians to the subject, with the result that many individuals and corporations at once began experiments and investigations. The work done has been widely scattered, often isolated, and frequently private as well as secret. About thirty processes for retorting are known to be in a greater or less stage of advancement. Of these the following are far enough advanced to be emphasized. Others might be included, if information about them were obtainable.

J. B. Jenson, Edcation Process—822 McIntyre Bldg., Salt Lake City, Utah.

Pearse Process—Arthur L. Pearse and Co., 50 East 42nd St., New York City, N. Y.

Scott Edcation Plant—Detroit Testing Laboratory, 674 Woodward Ave., Detroit, Mich.

Stalmann Process—Otto Stalmann, 319 Ness Bldg., Salt Lake City, Utah.

Wallace Process—George W. Wallace, Consulting Engineer, East St. Louis, Illinois.

Galloupe Process—Galloupe Process Co., Grand Junction, Colorado.

Simpson Process—Louis Simpson, 172 O'Connor St., Ottawa, Canada.

Wingett Process—American Shale Refining Co., First National Bank Bldg., Denver, Col.

Chew Process—National Shale Oil Co., 1530 Welton St., Denver, Col.

Prichard Process—Dr. Thomas W. Prichard, 52 East 41st St., New York City, N. Y.

Bishop Process—James A. Bishop, 1526 N. LaSalle St., Chicago, Ill.

Catlin Process—Catlin Shale Products Co., Elko, Nevada. R. M. Catlin, Franklin, New Jersey.

Del Monte Process—C. A. Prevost, 814 Southern Bldg., Washington, D. C.

Anderson Process—The Anderson Shale Oil Co., 160 South Broadway, Denver, Colo.

Brown Process—H. L. Brown, 265 Washington Ave., Newark, N. J.

Randall Process—The Lackawanna Oil Shale Co., Gas and Electric Building, Denver, Colo.

The Elko Shale Plant

The plant at Elko, Nevada, was erected by the Southern Pacific Company under the general supervision of the United States Bureau of Mines and the personal direction of Dr. David T. Day, of the Bureau. Dr. Day secured drawings of a Pumpherston retort from Scotland and erected a plant one mile east of Elko. The plant consists of a bank of four retorts, each of two sections; the upper one, made of cast iron, is fifteen feet high, and the lower section, of fire brick, twenty feet high. The shale is hauled on trucks from the mine, three and one-half miles away. The plant was completed in November, 1919, but no reports are yet available.

Catlin Plant, Elko, Nevada

The Catlin Shale Products Co. has been experimenting for the past three years at Elko, Nevada. The shale deposit is 6 feet thick, dips at an angle of 25 degrees, and averages 50 gallons of oil to the ton. The only mining of shale to a depth sufficient to give information of underground conditions has been done here. An inclined shaft was put down to a distance of 370 feet, with drifts at the 100, 200, and 300 foot levels. The use of 25 per cent powder—low freezing dynamite—gave satisfactory results. No change in the character of the shale was found in any part of the workings from the outcrop to the lowest faces. No timbering

has been needed and the roof has remained intact for three years. The record of accounts shows that from seven to ten tons of shale can be produced daily for each man employed underground—machine men, trammers, muckers, and boss—at an average cost of $1.25 a ton. Auger drills are used. No gas has been found. The shale is run out of the mouth of the mine, broken to three-inch size by spiked tooth rolls, and all, fine and coarse, is fed into the top of the retorts. The retorts are eight in number, arranged in a circle, 16 feet high, 54 inches in diameter, and covered with non-conducting material. The retorts have a combined capacity of 100 tons a day or 5,000 gallons of crude oil. Heat is applied at 850-900°F. The feed is intermittent. The units of the plant are as follows: retorts, condenser, oil stills, agitator, wax plant, gas producer, and storage tanks. The crude oil has a pronounced paraffin base and produces the following marketable products: distillate, kerosene, lubricating oil, wax, and gasoline. Water for the plant is pumped from the Humboldt river, a distance of 4,600 feet to an elevation of 300 feet. Raw shale is burned successfully under the boilers. The oil and gas vapors are drawn from the retort at a point two feet from the top and carried to the condenser. The spent shale from the bottom of the retorts is carried to a gas producer where sufficient additional gas is produced for the use of the plant. Even though all the experimental work thus far

has been done on a commercial basis, yet the company regards the work as still experimental and has made no formal report of details and actual results.

Colorado

At Grand Valley, Colorado, the Consumers Oil and Shale Company of Chicago and the Grand Valley Oil and Shale Company have spent $25,000 in building roads to their property, preparing building sites, erecting buildings, all preparatory to erecting a 150-ton retort. The total cost is expected to be $150,000. In the Grand Valley region alone there has already been expended more than $100,000 in acquiring land, building roads, carrying on experimental work, and in the various expenses incidental to a new industry.

The Mt. Logan Oil Shale Mining and Refining Company at De Beque, Colorado, has in process of erection a Simplex retort of commercial size, manufactured by the Stearns-Roger Manufacturing Company, Pueblo, Colorado.

The Continental Oil Shale Mining and Refining Company has completed a 50-ton plant, known as the Colorado Continuous Shale Process, designed by Hartley and Dormann, Engineers, Denver, in Rio Blanco County, Colorado, and has made a successful run. Bad weather and deep snow have, however, prevented further work till the spring of 1920, when the company expects to renew operations and to run continuously on a commercial scale.

At the Colorado School of Mines, Golden, Colorado, three retorts—experimental, but of commercial size—are in the process of erection. These retorts will enable tests on a commercial scale to be made for the general good of the industry.

Utah

The Bureau of Mines has established an oil shale laboratory at the University of Utah, Salt Lake City, Utah, for general scientific investigation of oil shales, but no report of the work done is now available. The Ute Oil Company of St. Louis, Mo., is erecting and has nearly completed, a complete retorting and refining plant 14 miles from Watson, Utah, to cost $350,000. The structure is of concrete and steel with automatic mechanical equipment throughout. The capacity is rated at 400 tons daily. At Dragon, Utah, the Western Shale Oil Company has completed the first unit of a 50-ton plant. The surface shale yields 50 gallons of oil to the ton.

CHAPTER IV

MINING

The methods of mining any particular deposit of shale must be adapted to local conditions. Two methods suggest themselves — the open cut and the underground. Open cut work will be used in certain special localities around Watson, Utah, Grand Valley, and De Beque, Colorado, and Carlin, Nevada, where there is little overburden, where steam shovels may be used, where the average oil content of the entire deposit is of commercial grade, where sites for the retorts are available, and where there is ample dumping space. In such favorable localities the cost of mining will be very low. In localities where there is a rich stratum of shale from 10 to 20 feet thick, giving 50 to 60 gallons of oil to the ton, it may be deemed more advantageous, for practical and economic reasons in the early stages of the industry, to mine the richest shale first. In such cases underground mining—the room and pillar method of coal mining operations—will probably be adopted. In this method of mining, adits are cut into the beds of coal; at intervals cross cuts are made at right angles to the adits, and from

Methods

OIL SHALE. UTAH

MASSIVE SHALE. COLORADO

these so-called rooms are turned off. Pillars of a size necessary to support the roof are left along the adits, the cross cuts, and the rooms. A large percentage of shale must be left, but this is inconsequential on account of the great extent of the deposits. It goes without saying that to open an underground oil shale deposit properly, a definite plan of development must be outlined, mechanical ventilation supplied, provision made for rapid and economical haulage, and the numerous appliances provided for handling a very large tonnage in an efficient and economical way. In the mining of coal the size and form of the coal as mined has a commercial importance. Not so in the case of shale, where all goes to the spiked rolls and is broken to size for the retorts. Hence, powder can be more fully used than in mining coal, the cost of mining thereby reduced, and the tonnage increased.

Breaking

The ordinary roll of jaw crushers or ball mills used to crush metallic ores do not seem to apply well in reducing shale to a size suitable for the retorts. Some American firms have placed crushers on the market which appear to do satisfactory work. The Scotch type which has proved successful is that of spiked rolls. The spikes are placed spirally on the rolls, and are removable so as to make repairs, in case of breakage, without serious loss of time. In reducing metallic ores crushing is not objectionable. In reducing shale the fundamental principle to be followed is that shale must be broken, not crushed.

Reducing devices that follow this principle will probably succeed. Spiked rolls are based on this principle, but other forms are not impossible. Experience in Scotch plants has shown that more satisfactory results are obtained in the distillation of oil shale, if the fine material, say less than 0.25 inch in size, be screened from the bulk of the broken shale and the two screened products be treated separately. The fine material is not sent to the distillation plants for treatment as a rule, but is used in the mines for filling purposes.

Mining Regulations

A new industry must be classified so as to come under established laws. The mining of shale, whether open cut or underground, will come under the Federal and State mining laws. A retorting plant will be classified as a metallurgical operation and will come under the same regulations. Some coal mining men are fearful that in mining shale explosive dust will be formed and accidents will follow. However, the deepest mining of shale in the United States, 370 feet at the Catlin plant, Elko, Nevada, has resulted in no dust nor gas explosions. The literature of the shale industry in France and Scotland for nearly seventy years, contains no account, as far as known, of dust or gas explosions, even though powder has been used.

Up to the present time thorough miner-like sampling of the oil shale, in a large and conclusive way, has not been possible. Natural difficulties have prevented. The slopes below the per-

pendicular cliffs can be easily scaled, but to sample, by a groove, a hundred or more feet of perpendicular cliff without being let down from above, is well-nigh impossible. In places where descending streams have cut into the rock, access is possible to the higher strata, but on the whole such sampling is incomplete and not altogether satisfactory except for preliminary investigations. The most satisfactory method of sampling these strata is by means of the diamond drill. The equipment for this work can be obtained sectionalized so that it can all be carried on burros or mules, by trail to the mesa ground above the oil shale beds. Here the equipment can be installed and a diamond drill hole can be put down as far as desired. Since the diamond drill produces a solid core of the rock it pierces, the width of each stratum passed through can be accurately determined. Also the core will furnish a sample of shale large enough to be tested and the oil content determined. In this way a large acreage can be cheaply and efficiently sampled, the thickness of each stratum of oil shale measured, the oil value of any and every stratum determined, and the total value of the acreage accurately estimated. Such knowledge would be an intelligent guide to the cheapest method of mining, whether the entire hillside by the open cut method, or the underground mining of the richest seams.

Testing Oil Shale Ground

The oil leasing bill approved February 25, 1920, contained the following sections applicable to oil shale deposits.

Leasing of Oil Shale Land

Section 21. That the Secretary of the Interior is hereby authorized to lease to any person or corporation qualified under this Act any deposits of oil shale belonging to the United States and the surface of so much of the public lands containing such deposits, or land adjacent thereto, as may be required for the extraction and reduction of the leased minerals, under such rules and regulations, not inconsistent with this Act, as he may prescribe; that no lease hereunder shall exceed five thousand one hundred and twenty acres of land, to be described by the legal subdivisions of the public land surveys, or if unsurveyed, to be surveyed by the United States, at the expense of the applicant, in accordance with regulations to be prescribed by the Secretary of the Interior. Leases may be for indeterminate periods, upon such conditions as may be imposed by the Secretary of the Interior, including covenants relative to methods of mining, prevention of waste, and productive development. For the privilege of mining, extracting, and disposing of the oil or other minerals covered by a lease under this section the lessee shall pay to the United States such royalties as shall be specified in the lease and an annual rental, payable at the beginning of each year, at the rate of 50 cents per acre per annum, for the lands included in the lease, the rental paid for any one year to be credited against the royalties accruing for that year; such royalties to be subject to readjustment

at the end of each twenty-year period by the Secretary of the Interior: Provided, That for the purpose of encouraging the production of petroleum products from shales the Secretary may, in his discretion, waive the payment of any royalty and rental during the first five years of any lease; Provided, That any person having a valid claim to such minerals under existing laws on January 1, 1919, shall, upon the relinquishment of such claim, be entitled to a lease under the provisions of this section for such area of the land relinquished as shall not exceed the maximum area authorized by this section to be leased to an individual or corporation: Provided, however, That no claimant for a lease who has been guilty of any fraud or who had knowledge or reasonable grounds to know of any fraud, or who has not acted honestly and in good faith, shall be entitled to any of the benefits of this section: Provided, further, That not more than one lease shall be granted under this section to any one person, association, or corporation.

Sec. 37. That the deposits of coal, phosphate, sodium, oil, oil shale, and gas, herein referred to, in lands valuable for such minerals shall be subject to disposition only in the form and manner provided in this Act, except as to valid claims existent at date of the passage of this Act and thereafter maintained in compliance with the laws under which initiated, which claims may be perfected under such laws, including discovery.

CHAPTER V

RETORTING AND REDUCTION

Petroleum, whether obtained from wells or resulting from retorting oil shale, is a mixture of hydrocarbon compounds. These belong to one of two series—the paraffin, or the olefine series. Those which consist chiefly of the paraffin series are designated paraffin base oils; those which consist chiefly of the olefine series are designated as asphalt base oils. Some oils are distinctly paraffin base oils, some asphalt base, and some mixtures. Thus the shale at Elko, Nevada, has a decided paraffin base, but that at Carlin, Nevada, an asphalt base. Most of the shale of Colorado, Utah, and Wyoming, however, have a paraffin base, though they carry some asphaltum. The curly strata in Parachute creek, Colorado, carry about five per cent of asphaltum.

Nature of Shale Oil Petroleum

In the present pioneer stage of the oil shale industry, the importance of the retort cannot be overestimated; it is the key to the entire situation. That shale has been successfully retorted and the crude oil refined in Scotland for nearly seventy years is no reason in itself that the same process, successful

Importance of the Retort

there, can be bodily transplanted elsewhere and be successful. Varieties in the character of the shale, climatic and economic conditions, and the available markets for the products all combine to make the solution of the problem unique. Because of this condition, American engineers and chemists of the highest ability—and some not so able—have been busy, during the past few years, in trying to devise a retort that will treat American shales successfully. What is needed is a simple retort which is economical in construction, treats the maximum tonnage per day, and is constructed not primarily for the purpose of producing by-products with all the expensive complications that go with them, but designed for the special purpose of producing the maximum amount of crude oil. It is important that this oil be not spoiled in the making, but be of a superior quality. Such a retort will undoubtedly secure some of the by-products. It may be desirable, in certain localities where the nitrogen content is high, to secure not only the maximum of oil, but also the maximum ammonium sulphate and to make special effort to this end in the construction of a retort. Scotch practice has not advanced materially in recent years, so that there is a wide and fertile field for experimentation and research.

In order to get an idea of what occurs in the process of producing oil from shale a few principles and laws of organic chemistry must be made clear. A hydrocarbon is primarily a compound

of the elements hydrogen and carbon, but combinations of these two with other elements are not excluded. Hydrocarbons occur from the simplest to those of the most complex nature and are almost limitless in number. Some are gases, others liquids, and still others are solid. The hydrocarbons in petroleum and shale oil may be divided into two general classes, saturated and unsaturated. In the saturated compounds the carbon element has absorbed or combined with all the hydrogen possible. Unsaturated hydrocarbons contain carbon that still has reserve power to combine with hydrogen. Shale oil consists mainly of liquid or dissolved hydrocarbons. A large proportion of these hydrocarbons are saturated, but unsaturated varieties are also always present. These are undesirable and must not be present in the refined oil. The first process of producing oil from shale is known as destructive distillation, or primary decomposition. If, however, the vapors are subjected to further great heat, secondary decomposition results. Secondary decomposition is undesirable. The chemical processes involved are complex and not easily understood by the layman, but a homely illustration may help. Speaking popularly, we may say the shale must be cooked. The ingredients to form bread—flour, water, salt, yeast, sugar, milk, and shortening—are mixed and form dough. But dough is not bread until it is cooked; then it becomes bread. So it is with shale. The organic

Chemical Principles

ingredients of oil and gas—called kerogen—are in the shale. When the shale is cooked, technically destructively distilled, oil and gas are the resultants.

The Destructive Distillation of Oil Shale

The oil shale industry will unquestionably become of enormous importance in the near future, and may be said, even now, to have passed the experimental stage. The industry in Scotland has been in profitable existence nearly seventy years, but the methods used are apparently not well adaptable to American shales, so that much experimental work has been done in this country to determine the most economical and most productive methods of treating our oil shales. Satisfactory results have been attained in a number of cases and experimental plants have been installed that bid fair to lead to commercial success. Notwithstanding the excellent results that have been realized in some of the experimental researches, much still remains to be done. Not all the factors for commercial competitive success have been demonstrated or necessarily attained. Disseminated more or less thickly through oil shale is a substance of a hydrocarbon nature, to which the name kerogen has been given. This is the source of the oil. When the shale is subjected to sufficient heat in a retort, that is, destructively distilled, the kerogen is decomposed into a number of products, mostly volatile, of which the most important, commercially, are oil, ammonia, and permanent

inflammable gas. These may be recovered from the escaping vapors and separated from each other by a suitable system of condensation and absorption. The oil resembles well petroleum, the ammonia forms the basis of a valuable fertilizer, and the gas may be utilized as at least a partial source of heat in conducting further operations.

The oil and gas, themselves hydrocarbons, result from the decomposition of the original hydrocarbons in the shale. The ammonia is produced from combined nitrogen which is always found in the shale in small amount. The temperature necessary for the destructive distillation of the kerogen in the shale may be roughly indicated as follows: at 212°F. a little gas begins to be evolved, but the decomposition is slight until a red heat is approached. At 750°F. the distillation may be carried to completion. The spent shale is designated as carbonized and is colored black by deposited carbon. A temperature of about 700°F. is probably all that is actually necessary for complete decomposition.

To obtain uniform products distillation is by no means a simple procedure. It is found that the same shale will yield varying amounts of oil and other products by simply varying the conditions of the distillation. The more oil produced, the less gas, and vice versa. Furthermore, the larger the yield of oil the better its quality. Since oil is the most valuable product, the conditions of the distillation that will result in the maximum yield of

oil is of the greatest importance. Both petroleum and shale oil consist mainly of liquid hydrocarbons; the hydrocarbons not liquid at ordinary temperatures are dissolved in the others. These hydrocarbons may be divided into two varieties, saturated and unsaturated. Most of the hydrocarbons in petroleum and shale oil are of the saturated variety, but there are always some of the unsaturated hydrocarbons present. They are undesirable constituents, as they have not the stability of saturated compounds and are liable to decompose and communicate color and odor to any colorless distillates containing them. They are therefore to be removed as far as possible by refining, which is, of course, an item of cost and loss of oil. The more unsaturates present the less refined oil is obtained per gallon of crude.

All shale oil contains unsaturated compounds; the amount present in different samples of oil from the same shale may be quite variable, and depend upon the conditions of distillation. They are some of the results of the process called cracking, whereby saturated compounds, under the action of sufficient heat, are more or less broken up or cracked into other compounds. No way of distilling oil shale has yet been found that yielded oil free from unsaturates. They appear to be produced at the outset, during what may be termed the primary decomposition, but their formation may not stop at this point. If the vaporized oils, in escaping from the retort, encounter greatly in-

creased heat, a secondary decomposition or cracking takes place with the production of an increased amount of unsaturated compounds. Furthermore, if the vapors are allowed to cool; and perhaps partially condense, before leaving the retort, as in the upper part of a charge, some of the condensed oil may drip back into hotter places and suffer re-vaporization, and the remainder will eventually all be re-vaporized as the place of condensation gets hotter or the charge settles. This re-vaporization results in more cracking and the production of more unsaturated compounds. In other words, the best quality of shale oil, as originally formed at a proper heat in the primary decomposition, will crack more or less, with the formation of an increased amount of unsaturates, if redistilled, or if its vapors are subjected to overheating. Since this is the nature of shale oil in its relation to heat, the necessary conditions for producing the maximum yield are indicated.

First, the distillation should be conducted at the lowest practicable temperature, to lessen the primary cracking of the oil vapors as much as possible. Secondly, secondary decomposition, or additional cracking of the evolved vapors, should be prevented by seeing that they are not overheated during their escape from the retort, and, also, by not permitting them to condense, so as to require re-vaporization before their final escape. A method of distillation, properly carried out on these lines, should yield the maximum quantity of

oil, and oil of the best quality. In one of the recently constructed American experimental plants, these considerations are recognized and provided for. The inventor claims to have obtained from 20 to 30 per cent greater yield of oil from the same composite sample of shale than when the volatile products were not so protected. He used dry heat alone, and the invention embodies the peculiar construction of the retort, the method of applying heat, the arrangement for withdrawing the vapors without condensation or overheating in the retort, and a consideration of the amount of shale to be economically carbonized at one time.

Consider what may be expected to happen if oil shale is distilled in a vertical iron retort, with top exit, without special precautions. Let the retort be two-thirds full of broken shale and a strong heat be applied at the bottom and all around the lower outside. The shale next to the walls distills first, while the interior portions and top are still comparatively cool. The outside shale will become carbonized and spent, shrinking somewhat from the walls, while the interior portions still are distilling. The vapors from the interior portions will seek the easiest channels of escape, which are out through the hot spent shale and up against the hot walls through the shrinkage space. The conditions are thus seen to be unfavorable for producing the maximum yield of oil. Unsaturates and gas will be formed in undue amount, at the expense of good oil.

It is claimed that steam must be injected into the retort for various reasons. It has been shown that, both in experimental work and in European commercial plants, the use of steam has diminished the amount of unsaturates and increased the yield of ammonia. In the Scotch process, for example, it is stated that without steam the amount of ammonia is lessened and other nitrogen compounds, of an undesirable nature, such as pyridine, are formed. In cases where steam has appeared advantageous or necessary, no special attention appears to have been paid to carry out the distillation along what appear to be the best lines. While the question is still a mooted one, it may be well to consider carefully the possible effect of steam.

First, as regards the oil. It may act simply to equalize the temperature, preventing the formation of places that are too hot and too cool, thus diminishing the production of unsaturates. Second, as regards ammonia. Nitrogen, in combination, exists in oil shale in appreciable quantity, perhaps as complex ammonia compounds or otherwise. During the distillation, the ammonia compounds may give off ammonia, either free or in combination. Free nitrogen and hydrogen, at the moment of their production, may unite to form ammonia. One recent investigator claims his experiments show that practically all the available ammonia may be obtained without the use of steam if proper temperature conditions are observed. According to his tests the most favorable tem-

perature for obtaining the maximum yield of ammonia is about 735°F. If the ammonia once formed is subjected to a further increase of temperature, it is liable to be more or less decomposed into its constituents, nitrogen and hydrogen. It will begin to decompose at a little below 940°F., and at about 1440°F. the decomposition is complete. Where the temperature is not otherwise controlled, it is thus possible that if steam is used it again acts as an equalizer. By preventing excessive cracking of the oil vapors it may also prevent the occurrence of the conditions under which the undesirable nitrogen compounds are formed, at the same time preventing the decomposition of any ammonia once formed. It is difficult to see how steam can aid in the formation of ammonia during the distillation of the oil by any chemical interaction.

There is said to be a small amount of nitrogen that remains in a non-volatile condition in the spent shale. Steam could probably form ammonia from this at a sufficiently high temperature by interaction with the carbon also always present, but in American shales the nitrogen that might thus be utilized is said to be very trifling, perhaps one-tenth of one per cent, or less, of the residue. Notwithstanding the theoretical considerations that indicate steam as unnecessary, if proper heat conditions are otherwise maintained, it remains a fact that experimental plants recently constructed, or now under construction, provide for the intro-

duction of steam to the retort, should occasion appear to demand it.

Where steam is used, a number of disadvantages are said to arise, the most important of which may be enumerated as follows: It is customary to use as much as one-half ton of steam for each ton of shale retorted. The volatile products coming from the retort are thus so increased as to require a condensing apparatus several times larger than would be otherwise required. This increases the cost of condensation by a like amount. The heat units carried away from the retort by the steam nearly equal what are required to decompose the shale. Oil and water are condensed together and form an emulsion that is very slow in separating by settling. This necessitates increased storage facilities and involves loss of time. On account of these alleged disadvantages it would seem inadvisable to use steam if its use can be avoided. However, the question still appears to be a mooted one and it would be unwise to consider it settled.

Another matter of importance in the distillation of shale relates to the thickness of the mass of shale that can be economically treated. Shale is a very poor conductor of heat and there is evidently an economical limit to the distance heat must penetrate to completely carbonize the shale farthest from its source. Suppose a mass of shale broken to 1.50 inch fragments be placed between two vertical iron walls and heated from one side

only until completely spent or carbonized. When the horizontal thickness of the bed is six inches twice as much heat is required as when it is only four inches. In other words, an increase of fifty per cent of thickness necessitates one hundred per cent more heat. Two beds of four inches thickness will therefore require no more heat than one bed of six inches. This matter evidently requires careful consideration in the construction of a retort.

Up to this point, the shale is regarded to be at rest, that is, not agitated, while being distilled. Although the principles thus far formulated appear to apply with equal force in any case, the devices for attaining the end in view may vary greatly. Horizontal retorts have been devised in which the shale in an upper retort is gradually moved by screw conveyors into a second and third retort placed underneath. Heat is applied to the lowest retort and passes upward to the others. Thus a gradual heating of the shale is effected, and while complete carbonization may take place only in the lowest retort, the heat in the others may be sufficient to start the distillation of the lighter oils, which, if desired, may be withdrawn from the retorts where they are produced and condensed separately and thus effect a partial refining during the primary distillation. The comparative economic value of any devices for the distillation of shale can be determined, of course, only by practical testing on a fairly large scale.

The principal apparent requirements in the distillation of oil shale in order to obtain the maximum yield of oil, and that of the best quality, may be summarized as follows:

Requirements for a Successful Retort

1. Use of the lowest possible heat in the distillation, so as to have a minimum of primary decomposition or cracking of the oily vapors.

2. Avoid overheating and the ensuing secondary decomposition of the vapors during their escape from the retort. This consideration is of the highest importance.

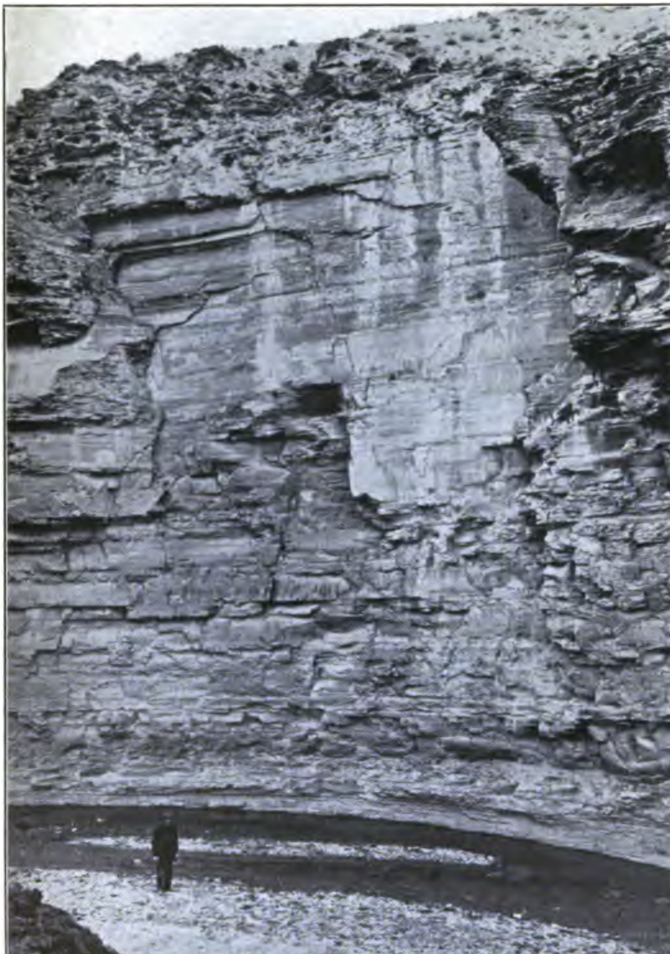
3. Avoid any condensation of oil in the retort, necessitating re-vaporization with the production of undesirable products on account of secondary decomposition.

4. Consider the alleged disadvantages attributed to the use of steam and avoid its use if possible.

5. As an economic consideration, take into account the thickness of the mass of shale to be most economically treated at one time.

In addition to the technical features necessary in a retort certain practical and economic considerations are worthy of notice.

a. The site of a retort should be so selected that the supply of shale be well above the breakers and yet, below the retorts, there should be ample dumping ground. These two factors are necessary in order to reduce the cost of moving the



OIL SHALE CLIFF. UTAH

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OIL SHALE. COLORADO

shale to the retorts and disposing of the spent shale. The importance of a good site cannot be emphasized too strongly because, from the mechanical point of view, shale retorting consists, in part, of moving a hill from one place and putting it in another.

b. The retort should be placed as close as possible to the shale to be treated. The most favorable location is beside an outcrop where all the shale above the retort is of commercial value, can be quarried, and run at once through the retort. The next favorable location is just below the outcropping of a rich stratum of shale. In this case the shale must be mined and an extensive system of underground work planned.

c. If possible, the feed should be continuous and not only the oil and gas removed continuously, but also the spent shale.

d. Another practical consideration that must not be overlooked is an ample water supply. This may be obtained from valley streams, from impounded waters, or from wells, but it must be obtained, for without it a shale deposit would be valueless.

e. Other factors such as good wagon roads, nearness to railroads, timber, labor supply, camp facilities, and similar features are all worthy of consideration, but are not so essential in the early stages of the industry as the technical features and the first three considerations.

f. From the chemical and physical laws which

govern the action of distillation it is evident that the process must be carried on in fairly small units, but a complete plant will consist of many such units. Consequently, the unit should have as large a daily capacity as possible.

g. Since the industry is one of large tonnage, hand labor should have little or no place in a plant. Accessory machinery should be automatic, mechanical, and, as far as possible, fool proof.

It is proposed in one American process to meet these requirements by means of a horizontal retort built in sections; shale is fed in at one end continuously, kept at a depth of from 1.50 to 2 inches, and advanced by means of a series of transverse baffles; heat is furnished by nichrome heating elements imbedded beneath the floor of the retort; the temperature can thus be controlled so that each section of the retort can be heated to any required degree; at the top of each section is an outlet for the oily vapors as soon as they are formed: the gas produced is used in an internal combustion engine which operates a dynamo for the production of the electric current needed.

The first commercial plants will undoubtedly be erected in choice locations, where the natural advantages are the best. It should be noted, however, that there is a great difference between such favored plants, erected under the most favorable conditions, and the development of the oil shale industry on a scale large enough to replace the present huge well petroleum industry.

Scotch Shales Compared with American Shales

Although the production of oil from shale has been a profitable industry in Scotland since 1850, it is not to be assumed that the methods so successful there can be introduced here with equal success. Just as a single method of producing copper from ore will not apply equally well to all copper ores, so a single method of retorting oil shale will not apply equally well to Scotch shale and to all varieties of American shale. There are greater differences between American shales themselves, than between any one of them and the typical Scotch shale. The style and method of retorting must, therefore, be determined, by experiment, to fit the character of shale to be treated. The main differences between the characteristic Scotch shale and the American shales are these: In the Scotch shales the silica content is low, and the alumina content high, but in the American shales silica predominates and the alumina is low; the Scotch shales uniformly contain more nitrogen than the American shales, but the American shales uniformly produce more oil: in the American shales the oil content is sufficient to make oil production commercially profitable with ammonium sulphate a by-product, but in Scotland the oil content is too low to be profitable without the ammonium sulphate. Thus the relative positions of oil and ammonium sulphate are not the same in the two countries. The Scotch shales, as now worked, do not yield, on the aver-

age, more than 15 gallons of oil to the ton. American shales over large workable areas will yield 42 gallons to the ton. The Scotch shales lie far below the surface, are in irregular beds, faulted and folded, and vary greatly from place to place in oil content. American shales, on the other hand, in Colorado, Utah, and Wyoming especially, lie from one thousand to twenty-five hundred feet above the river beds, exposed as horizontal strata in vertical cliffs, easily mined, and are of comparatively uniform oil content over large areas. American shale oil yields a higher percentage of gasoline, motor oil, and kerosene than the Scotch crude shale oil; an equal amount of lubricating oil and gas oil; but less ammonium sulphate.

Pumpherston (Scotch) Retort

A standard Scotch (Pumpherston) retort is composed of two main sections, one above the other. The upper one is constructed of iron, 15 feet high; the lower one of fire brick, 20 feet high. Shale is fed in at the top and, in the iron section, is subjected to a heat of from 750 to 900°F. Here the oil and gas are distilled. The shale then is let down to the lower, or fire brick, section where it is subjected to a temperature of 1300°F. or more. Steam is injected and ammonia is produced by the hydrogen in the steam uniting with the nitrogen in the shale. The typical American retort will probably be constructed on simpler lines than the Scotch retort. But even for the various American shales modifications in the construction of

the retort are required for the different characters of shales. Their behavior is not always the same when subjected to heat and superheated steam, although a preliminary examination in the laboratory may not suggest this.

Condenser

In Scotland the condensation of the gaseous products issuing from the retorts is accomplished by passing them through a long and extensive series of pipes exposed to the atmosphere, the temperature of which is depended upon to cool and consequently condense the vapors. It is probable, however, that a more efficient type of water cooled condenser will be adopted in this country, on account of the climatic conditions, which vary greatly between Scotland and our western country.

Ammonia Scrubber Plant

The scrubber consists of a vertical pipe approximately 24 inches in diameter and 30 feet high. With exception of the upper and lower parts, four feet long each, the pipe is filled with diamond shaped wooden baffles, placed in alternate layers at a small distance from each other, in such a manner, that each baffle in a layer covers a corresponding opening in the succeeding upper and lower layers of baffles. The permanent gas from the condenser enters the pipe column near its bottom and, ascending through the layers of baffles, meets a descending spray of water, which absorbs any ammonia that may be still left in the permanent gas. The resulting ammonia water, which may be

re-used for this purpose, leaves the pipe column near its bottom by a pipe line, which transports it to the storage tanks for ammonia water for treatment in the sulphate of ammonium precipitating plant. The gas, after ascending over the baffles in the pipe column, leaves the latter at its top by a pipe line which conducts it to the bottom of a similar pipe column, also filled with baffles as described.

Gasoline Absorption Plant

The gas, in its ascent over the baffles, meets a spray of oil entering at the top of the pipe column and descending over the baffles towards the bottom of the column pipe. The oil used for this purpose is specifically heavier than gasoline and absorbs any of the latter that may be present in the gas. It has been found that from two to four gallons of gasoline may thus be extracted from the gas per thousand cubic feet of the latter, or from four to eight gallons per ton of western oil. The final permanent gas, deprived of its gasoline, leaves the pipe column at its top and is conducted to the gas reservoir, to be eventually used as fuel.

The oil charged with the gasoline absorbed from the gas may then be treated in the plant used by the United States Geological Survey, in making tests on a commercial scale for the extraction of gasoline from natural gas. This plant, according to the statement of the Geological Survey, has given very satisfactory results and is simple and economical as far as installation and operation

are concerned, and is adapted to the needs of an oil shale plant of one hundred tons daily capacity. It operates as follows: The oil, charged with the gasoline absorbed from the gas, is first conducted to a horizontal so-called weathering tank—an ordinary plate steel cylinder, one foot six inches in diameter and twelve feet long. This tank has a relief valve at its upper circumference, through which the lighter parts of the gasoline escape as vapors, which may be conducted to a heat exchanger, where it is preheated by the hot oil returning from the still to the absorbing tower for re-use. From this heat exchanger the preheated oil, charged with the gasoline absorbed from the gas, is conducted to a still operated by live steam. Here the gasoline is expelled from the oil and the vapors are conducted to a cooler box, where the water is separated from the gasoline. The latter goes to a condenser and the condensate, after refining, is ready for the market. The hot oil remaining in the still, after having been freed from the gasoline, is conducted through the heat exchanger, where it travels through pipes in the opposite direction to the cold oil charged with gasoline, passing to the still, preheating the latter liquid. After having transferred the great part of its heat to the oil passing to the still, it is conducted through water cooled coils to the absorption tower for re-use.

Ammonia liquor, which was formerly regarded as a nuisance, has meant, in many cases, the dif-

ference between success and failure in the Scotch treatment plants. Until 1865, the ammonia liquor which forms a large portion of the total distillate, was thrown away. Robert Bell, of Broxburn, is given credit for being the first to treat the water for the production of ammonium sulphate. Of the Scotch shales, those which produced small amounts of oil were generally those which produced the largest yield of ammonium sulphate. From preliminary examination of the shale of Colorado and other western states, the yield of ammonium sulphate from these sources is independent of the yield of oil. In producing ammonium sulphate from the liquor, the procedure is similar to that followed in gas works. The methods and apparatus devised by Beilby and Henderson are the most satisfactory. In the tower still of Beilby, the ammonia is expelled by raising the liquor to the boiling point by means of direct steam. The Henderson still effects the same purpose, but with a smaller amount of steam. The ammoniacal vapors are then conducted into what is known as the cracker box, which is a vessel containing sulphuric acid. As the absorption is usually not complete in the first box, the vapors are passed over into a second. The acid used in the first box is usually waste, recovered from different steps in the refining of the oil. The second box contains acid of 1.4 specific gravity, which insures complete conversion. The first crystals of ammonium sulphate are large

Ammonia Liquor

and may be dried by spreading in a suitable room; the smaller crystals are dried by means of centrifugal machines. The salt obtained is pure enough to be used as a fertilizer.

Sulphate of Ammonia Plant

The ammonia water coming from the separators, which segregated it from the oil, together eventually with the ammonia water coming from the scrubber, is conducted to a column apparatus, where the ammonia gas is evaporated. This column apparatus is constructed of ten sections of cast iron, twenty-four inches in diameter, twenty-eight feet high. The sections are provided with flanges at their ends and bolted together to form a vertical column of the size stated. Within this column there are seventeen shelves, at equal distances apart, cast in one piece with the sections. Three nozzles tapering from 2.5 inches in diameter to 1.5 inch and 4 inches long, are cast with the shelves. Extending upwards and over the shelves a hood or bell is fastened at a distance of about one-half inch above the orifice of the nozzles. The bottom of this bell is cut out zig-zag shape to a height of two inches in such a manner that the lower part of the mantle of the bell represents about one-half metal and one-half opening. A two-inch nipple extends from a point three inches above each shelf to a point about three inches below the shelf. At the seventh section from the top connections are made with a tank containing milk of lime. The ammonia water, after passing through

a heat exchanger, enters the column at the top and remains on the uppermost shelf to a depth of three inches, when it overflows into the two-inch nipple, which drops it onto the second shelf on which it also remains to a depth of three inches, when it passes to the third shelf by overflowing into the two-inch nipple which transports it to the fourth shelf and so forth over all seventeen shelves, until it passes to the bottom of the column, where it issues as waste, after having been deprived of its ammonia. At the seventh shelf from the top a connection is made with the milk of lime storage tank, from which such an amount of milk of lime flows into the seventh section from the top as has been previously determined by an analysis as necessary. Steam enters the column at the bottom and ascends through the tapering nozzles, being diverted by the top of the bell towards the bottom, where it enters the ammonia water, through the zig-zag shaped openings at the bottom of the bell, heating the water and driving off the ammonia gas. From the lower section the steam ascends to the next upper section through the tapering nozzle, operating in the same manner as described from shelf to shelf, until the remainder finally issues, together with the volatilized ammonia, from the top of the column into a standard steam separator, where it is separated from the ammonia gas, which, by means of a pipe line, is conducted directly to the precipitating tank.

The free ammonia is volatilized only in the upper six sections, while from the combined ammonia (ammonium chloride, ammonium carbonate) which is practically always present in the ammonia water, the ammonia must be set free by combining its impurities with lime. Ammonium chloride for instance, treated with milk of lime, furnishes calcium chloride, water and ammonia, according to the equation: $2\,(NH_4)\,Cl + Ca\,O = Ca\,Cl_2 + H_2\,O + 2\,N\,H_3$.

In a similar manner ammonium carbonate furnishes, in combination with lime, calcium carbonate, water, and ammonia, according to the equation: $(N\,H_4)_2\,C\,O_3 + Ca\,O = Ca\,C\,O_3 + H_2\,O + 2\,N\,H_3$.

The precipitating tank contains dilute sulphuric acid into which the ammonia gas is conducted, combining with the sulphuric acid to form sulphate of ammonia, according to the equation: $H_2\,S\,O_4 + 2\,(N\,H_4\,H\,O) = (N\,H_4)_2\,S\,O_4 + 2\,H_2\,O$.

The precipitating tank is built of wood and lined with lead. It has one sloping side, along which the crystals of sulphate of ammonium are removed to a draining floor or they are freed from moisture by a centrifugal machine. The sulphate of ammonium product is then dried and ready for the market. The reaction between the ammonia vapors and the sulphuric acid generates a large amount of heat, which generates steam, carrying some ammonia and fine particles of sul-

phate of ammonium along. For this reason, and also for the protection of the workmen, the reaction takes place under a bell, the top of which ends in a pipe which is connected with a trap, separating the particles of sulphate of ammonium from the steam, which then enters the heat exchanger to preheat the original ammonia water before it enters the column apparatus. The primary economic products of the distillation plant are therefore: crude oil, gas, and sulphate of ammonium.

An adequate supply of sulphuric acid for the absorption of the ammonia must be furnished. A production of 30 pounds of ammonium sulphate to the ton of shale will require approximately 25 pounds of sulphuric acid or 12,500 tons of 92 per cent sulphuric acid for each million tons of oil shale treated.

Gas

Gas results from the uncondensed portions of the vapors. Its composition varies with the nature of the material retorted, the design of the retort, the temperature of distillation, and the efficiency and nature of condensers. An idea of its nature may be had from the following analysis, as given in the "Journ. Soc. Ch. Ind.," 1897, p. 983:

Carbon dioxide	22.08	per cent
Oxygen	1.18	" "
Heavy hydrocarbons ...	1.38	" "
Carbon monoxide	9.77	" "

Methane	3.70	per cent
Hydrogen	55.56	" "
Nitrogen	6.33	" "
	100.00	per cent

The high proportion of hydrogen must be attributed to the action of steam upon the carbon of the spent shale. A large proportion of nitrogen indicates leaks of air admitted into the system. To obtain a maximum of heating value, the air admitted should be kept as little as possible. The greater the amount of nitrogen the lower will be the heating value. As the gas produced is used for the partial heating of the retorts, it is necessary to keep its heating value at the maximum point.

The Heat Value of Gas Produced

One ton of shale will produce on the average 2,500 cubic feet of gas of a calorific value of 507 B. t. u. Five hundred and seven by 2,500 gives 1,267,500 B. t. u. as the calorific value of the gas produced from one ton of shale. Colorado coals give an average of about 10,800 B. t. u.; 2,000 by 10,800 gives 21,600,000 B. t. u. to the ton of coal, or approximately 17 times that of the B. t. u. in a ton of shale. In practice coal is only about 60 per cent efficient, but gas is 80 per cent efficient; hence the heat value of the coal is reduced to 13 times the heat value of the gas from a ton of shale. In other words, for each 13 tons of shale mined suf-

ficient gas would be produced to do the work of a ton of coal. Thus, in a 400-ton plant enough gas would be produced daily to be equivalent to more than 30 tons of coal.

Gasoline

Crude shale oil produces a superior quality of gasoline. On account of the great present demand and the potential demand in the near future for gasoline this fact plays an important rôle in the success of the industry. Shale oil gasoline has a lower boiling point and weighs four-tenths of a pound more to the gallon than petroleum gasoline. Also, a gallon of petroleum gasoline gives 126,000 heating units compared with 134,000 from shale oil gasoline. Thus shale oil gasoline has an increased power per gallon and, on account of its lower boiling point, will give a more powerful explosion.

A complete oil shale plant is necessarily quite extensive and includes the following:

A Complete Shale Oil Reduction Plant

I. Mining

Mining camp; bunk houses, cook house, blacksmith shop, and machine shop; fans and ventilating equipment; ore cars; machine drills; tramway; general mining tools and mining equipment; spiked rolls or other breaking machinery; storage bins.

II. Retorting

Site so placed as to allow for additional units; retorts connected to the condensing system to con-

dense the vapors and oils; absorption plant to recover gasoline from the gases; scrubbers to remove the by-products from the gas.

III. Refining

(a) Stills for straight run refining; stills for re-running and finishing; stills for cracking gas oil into synthetic gasoline or motor spirit.

(b) Storage tanks for crude; run down tanks for various fractions and products; storage for refined products.

(c) Pipe lines from retorts to refinery and from refinery to railroad.

(d) Agitators and agitator house for acid and soda treatment of oils, and washers to remove them from the oil.

(e) Clay burning house, for purifying and renewing the "Kieselguhr" or diatomaceous earth used in the stills and filters.

(f) Pumping plant for pipe lines, and water supply for retorts and refinery, using a large amount of water for condensing and cooling.

(g) Wax plant, coolers, refrigerators, hydraulic and filter presses to separate the paraffin wax from the heavy distillate; sweating houses for paraffin wax refining.

(h) Loading racks at railroads, barreling, packing and shipping house, carpenters tool, and repair shop.

(i) Electric light plant for mines, retorts, and

refinery; also power plant for mining and pumping.

IV. Ammonium Sulphate Plant

In Scotland, "A three-story high ammonium sulphate house, with column-stills, acid saturators for the ammonia, vacuum evaporator, centrifugal driers, storing bins and grinding mills, sulphuric acid making plant; acid recovery plant."

CHAPTER VI

EXPERIMENTAL WORK

Need of Experimental Work

Although much experimental work needs to be done, and will be done, on oil shale before complete scientific knowledge—chemical and physical—will be obtained, and such exact scientific work should be encouraged, yet the practical need of the industry at the present moment is the erection and operation of retort units of commercial size. It is clear from the scientific principles already known that the retorting of oil shale will be done commercially in a large number of retorts each of which has a comparatively small daily tonnage capacity. The erection of one of these retorts of commercial size successfully operated will point the way to a daily capacity of a 1,000 tons a day by the mere duplication of the single retort. Hence, with the advent of such a retort, operated on a commercial scale, treating shale as it is mined, broken, and delivered to the retort, designed so as to permit automatic mechanical handling of the ore, tested and approved by impartial and competent engineers, there will be a red letter day in the history of the industry in the United States.

Experimental work has been done by the United States Geological Survey, the United States Bureau of Mines, the University of Utah, the Colorado School of Mines, and by many capable private companies, engineers, and chemists. Unfortunately, however, some would-be chemists, untrained and inexperienced, lured by the tales of immense quantities of oil shale waiting "only the touch of the chemist's wand" to transform it into oil, have attracted capital from persons less informed than themselves and have dissipated it in experiments that violate the laws of science in general and chemistry in particular. Such a condition is regrettable, but is inevitable in the early stages of a new industry.

Experimental Work of J. B. Jones, Petroleum Engineer

J. B. Jones, Petroleum Engineer, of Kansas City, has made an extensive study of oil shale both in the field at Grand Valley, Colorado, and in the laboratory. To test this district he took many samples and checked them by taking seven samples as cross cuts on the principal vein of the valley, of about 1,000 pounds in each sample, from which four hundred pounds average samples were run through the retorts. These samples were taken from half a mile to three miles apart and safely represent an average of the brown, massive shale of Parachute creek. The average of these seven samples showed a recovery of 67 gallons of oil to the ton. The lowest sample gave 52 gallons and the highest 93 gallons. As a result

it is fair to assume that this district will average 56 gallons to the ton for the massive or curly brown shales, about 30 gallons for the lean or light gray shales, and 45 gallons for the paper shales. For estimating purposes a general average of 42 gallons is used. The refining record on the Grand Valley oils was good and the products all of high quality. The paraffin wax had a melting point of 135 degrees in comparison with the average wax from petroleum which has a melting point of from 114 to 124 degrees. The higher the melting point, the more sale value it has. The Grand Valley lubricating oils showed an especially fine quality and were 50 per cent of the crude, of 395 flash—475 fire—with a viscosity of 410 at 100 degrees. From the Nevada crude shale oil he produced 46 per cent of lubricating oil and from the Colorado crude shale oil 50 per cent of the crude came through as a high grade motor oil. From the different shales he produced from the crude oil from 30 per cent up to 60 per cent of motor oil, or if he wished the highest possible amount of gasoline, he put the oil through any one of several successful cracking processes and produced up to 60 per cent of gasoline. The shale oil resulting from these tests was refined by the Wells Refining Process.

A shale oil lubricating distillate, just as it came from the stills, without any treatment or finishing and representing 57 per cent of the crude shale oil and showing a low viscosity—133 viscosity at

70 degrees—was submitted to the Ohio State University laboratories. It was tested in competition with a Standard Oil Company's gas engine cylinder oil, made from petroleum oil having a viscosity of 374 at 70 degrees. The results were as follows:

Standard Oil Co.'s make of gas engine cylinder oil used in test showed:

Gravity, Baumé	24.4
Flash	405.
Fire	485.
Viscosity at 70	374.
Color	No. 6

Shale oil used in test showed:

Gravity, Baumé	30.3
Flash	390.
Fire	455.
Viscosity at 70	133.
Color	No. 4

This oil was used on a 12-hour continuous run and the test record shows the following salient features:

a. The engine ran for one hour using the petroleum oil, and was run for 12 hours using the shale oil, in each case the revolutions per minute were 275 and the explosions per minute were 137.5.

b. The engine ran cooler using shale oil.

It required 50 pounds less jacket water per hour to cool the cylinder using shale oil.

400 pounds of jacket water, using shale oil, kept the temperature of jacket water from vaporizing

at 185, while it took 450 pounds an hour to keep it at 211 using petroleum (Standard Oil).

c. Engine carried a heavier load using shale oil.

Net brake load using shale oil was 40 lb.

Net brake load using petroleum oil was 38.2 lb.

d. Developed more horse power.

Brake horse power using shale oil, 6.28.

Brake horse power using petroleum oil, 6.

e. Mean effective pressure on piston.

Was less using shale oil, showing less friction and better lubrication.

Mean effective pressure shale oil, 37.80.

Mean effective pressure petroleum oil, 49.

f. Mechanical efficiency was better.

Mechanical efficiency shale oil, 54.5.

Mechanical efficiency petroleum oil, 52.4.

g. Engine friction was less.

Engine friction using shale oil, 4.87.

Engine friction using petroleum oil, 5.45.

h. Fuel used (to perform better service) was reduced 30 per cent when using shale oil.

Fuel used was kerosene; per indicated horse power, per hour, consumed 0.5 pound using the shale oil, while it consumed 0.647 pound using petroleum. Per brake horse power, per hour, consumed but 0.9 pound using shale oil and required 1.25 pounds of fuel oil using petroleum. The results of these tests show the superior lubricating qualities of shale oils, when properly produced and finished. It has been found from many tests that improper temperatures in the retorts and

high temperatures in the refining will ruin the natural excellence of the shale oils, so proper methods and processes in reduction and refining are an absolutely prime requisite for the production of superior products.

G. W. Wallace, East St. Louis, Ill., who has done much experimental work on oil shale, made a careful test of eight samples from Dragon, Utah, with the following results:

Tests on Oil Shale from Dragon, Utah

Sample No.	Weight of Charge in Pounds	Gallons of oil to the ton of shale	Pounds of Ammonium Sulphate to the ton of shale	Average Temperature of Carbonisation	Time Required to carbonise	Per Cent of Volatile matter in the shale
1...	80	66.50	9.14	492°F.	1 hr. 30 min.	31.0
2...	80	38.96	21.02	531	1 hr. 24 min.	30.0
3...	86	47.25	11.20	568	1 hr. 24 min.	30.2
4...	74	52.00	19.74	469	1 hr. 37 min.	36.4
5...	84	39.60	8.66	595	1 hr. 38 min.	28.6
6...	95	43.10	19.14	605	1 hr. 41 min.	33.7
7...	86	48.90	19.48	651	1 hr. 28 min.	28.0
8...	98	54.20	25.40	580	1 hr. 20 min.	35.7
Average...	87	48.10	17.20	573°F.	1 hr. 33 min.	31.9

The table on page 87 gives the important components of the shale oil recovered from these same eight samples of shale.

The distillate column represents all oil distilling between the gasoline fraction and the residue. The residue in all cases was of about the consistency of soft pitch, but, aside from being

Sample No.	Percentage of Gasoline	Percentage of Distillate	Pounds of paraffin to the ton	Percentage of Solid residue	Percentage of Water in the Oil
1....	16	73	31	8.0	3.0
2....	16	73	19	7.0	4.0
3....	30	78	23	6.0	6.0
4....	21	67	38	10.0	1.1
5....	18	63	19	9.0	1.0
6....	20	60	21	10.0	Trace
7....	18	68	23	7.0	None
8....	17	69	26	10.0	3.5
Average	18.25	71.33	23.0	8.48	1.94

black, had no pitch properties, but was more of a wax.

Test by the United States Geological Survey

In Bulletin 581-A of the U. S. G. S., E. G. Woodruff and David T. Day have reported in detail on numerous exposures of the Green River formation in Colorado. The following extracts show the results of tests and the nature of the oil-shale seams:

RESULTS OF FIELD DISTILLATION

No. of Test	Locality	Thickness of Shale Samples, Ft.	In.	Amt. of Shale Used, Pounds	Amt. of Oil Obtained, Gallons	Amt. of Oil to the short ton of Shale, Gallons
1	Conn Creek	1	4	100	3.1	62.2
2	Kimball Creek........	6	0	150	2.4	31.6
3	Kimball Creek (second test)...............	6	0	156	2	26.2
4	Parachute Creek......	5	10	150	1.5	20.0
5	4-A Ranch	5	10	150	.78	10.4

Exposure in Parachute Creek

Total exposure 110 ft. 7 in.
Sec. 29, T. 5 S., R. 95 W.

Thickness of Seams	Estimate
31 feet	20 gal. a ton
4 ft. 10 in.	20 gal. a ton
5 ft. 10 in.	20 gal. by field test

Section Along Mount Logan Trail

Sec. 26, T. 7 S., R. 97 W.
Total exposure, 1,086 ft. 10 in.

Thickness of Seams	Estimate
81 ft.	20 gal.
1 ft. 1 in.	20 gal.
8 in.	30 gal.
2 ft. 6 in.	25 gal.
9 in.	30 gal.
5 ft. 6 in.	20 gal.

Exposure at 4-A Ranch

Sec. 21, T. 6 S., R. 90 W.
Total exposure, 19 ft. 9 in.

Thickness of Seams	Estimate
5 ft. 3 in.	20 gal.
1 ft. 2 in.	25 gal.
4 in.	25 gal.

Exposure on the North Side of Kimball Creek

Sec. 5, T. 7 N., R. 100 W.
Total exposure, 86 ft.

Two samples, each from a seam six feet thick,

gave 31.6 and 26.2 gallons of oil to the ton, respectively.

Dean E. Winchester, in Bulletin 641-F, of the U. S. G. S., gives a number of stratigraphical sections from which the following are taken to illustrate the thickness of the shales.

T. 1 N., R. 103 W. Total thickness, 929 ft. 1½ in.:

In this exposure are 14 seams of 7 in., 1 ft., 1 ft., 4 ft., 1 ft., 1 ft., 2 in., 1½ in., 2 in., 5 ft., 4 in., 2 ft., 10 in., and 3 ft. thickness, respectively, all of which are estimated to carry 15 gallons or more of oil to the ton.

T. 1 N., R. 104 W. Total exposure, 765 ft. 3 in.:

In this exposure are 25 seams of 6 in., 1 ft., 6 in., 8 ft., 5 ft., 1 ft., 6 in., 5 ft., 1 ft., 2 ft., 1 ft., 2 ft., 1 ft., 1 ft., 6 in., 1 ft., 1 in., 1 ft., 2 in., 3 ft., 2 ft., 2 in., 1 ft., 1 in., 4 ft., and 1 ft., in thickness, respectively, all of which are estimated to carry 15 gallons or more of oil to the ton.

T. 1 N., R. 100 W. Total exposure, 399 ft. 4 in.:

In this exposure are 3 seams of 6 in., 1 ft., and 3 ft. thickness, respectively, which are estimated to carry 15 gallons or more of oil to the ton.

T. 1 N., Rs. 99 and 100 W. Total exposure, 874 ft. 9 in.:

In this exposure are 31 seams of 8 in., 1 ft., 7 ft., 1 in., 2 ft., 2 ft., 4 ft., 1 in., 6 in., 1 ft., 5 ft., 1 ft., 3 in., 6 in., 2 in., 1 ft., 2 in., 8 in., 8 in., 6 in., 1 ft., 1 ft., 6 in., 1 ft., 1 ft., 3 in., 2 ft., 6 in., 3 ft., 5 ft., 4 in., 3 ft., 3 ft., and 1 ft., in thickness, respectively,

all of which are estimated to carry 15 gallons or more of oil to the ton.

T. 2 N., R. 98 W. Total exposure, 1,677 ft. 1¾ in.:

In this exposure are 9 seams of 5 ft., 5 ft., 4 ft., 11 in., 3 ft., 7 in., 5 ft., 6 in., 1 ft., and 1 ft. in thickness, respectively, which are estimated to carry 15 gallons or more of oil to the ton.

T. 2 N., R. 97 W. Total exposure, 1,605 ft. 11½ in.:

In this exposure are 12 seams of 3 ft., 3 ft., 3 ft., 5 ft., 2 ft., 2 ft., 2 ft., 5 ft., 2 ft., 10 ft., 3 ft., 8 in., and 3 ft. in thickness, respectively, that are estimated to carry 15 gallons or more of oil to the ton.

T. 1 N., 97 W. Total exposure, 2,496 ft. 6 ½ in.:

In this exposure are 27 seams, 1 ft., 3 in., 3 ft., 1 in., 5 ft. 11 in., 3 ft., 2 ft., 3 ft. 4 in., 6 in., 5 ft. 8½ in., 2 ft., 6 in., 2 ft., 3 ft., 5 ft., 5 ft., 5 ft., 3 ft., 1 ft., 1 ft., 1 ft., 3 in., 2 ft. 4 in., 3 ft., 4 in., 5 ft., 8 in., and 4 ft. 4 in. in thickness, respectively, all of which are estimated to carry 15 gallons or more of oil to the ton.

In Bulletin 641-F of the U. S. G. S., Dean E. Winchester summarizes all the field tests in oil shales made by the survey as follows:

Summary of Tests

1913

No. of Samples	Amount of Oil to the Ton
1	10.4 gal.
8	16-40 gal.
	(Average, 27.2 gal.)

No. of Samples	Amount of Oil to the Ton
1	45.2 gal.
1	61.2 gal.
1914	
17	Less than 10 gal.
22	10-20 gal.
11	20-30 gal.
3	30-40 gal.
2	40.6 gal.
1	65.3 gal.
1	86.8 gal.
1915	
6	Less than 10 gal.
7	10-20 gal.
7	20-30 gal.
9	30-40 gal.
5	More than 40 gal. (1-90 gal.)

In a few samples only was the yield of ammonium sulphate determined. This was found to range from 18.3 pounds by dry distillation, or 34 pounds by steam distillation, to 0.4 pound to the ton of shale. The yield of inflammable gas varied from 500 to 4,549 cubic feet to the ton. Dean E. Winchester, in U. S. G. S. Bulletin 691-B, gives detailed results of 83 distillation tests made on the oil shale of the Uintah basin in Utah. Analysis of his results gives the following:

	Minimum	Maximum	Average
Thickness of the bed sampled .	6 in.	12 ft. 6 in.	4 ft. 5 in.
Yield of oil to the ton	1 gal.	90 gal.	23.70 gal.
Yield of ammonium sulphate to the ton.................	0.29 lb.	15.92 lb.	4.9 lb.

From these results a reasonable inference to be drawn is that the shale, over a large area, is of minable thickness and carries oil values of economic value, but that the amount of ammonium sulphate recoverable is too small to be worthy of commercial consideration.

In Bulletin 641, p. 156, he also gives the products of the fractionation of shale oil as follows:

Gasoline (distillate to 150°C)	7 to 12	per ct.
Kerosene (150° to 300°C)....	28.5 to 49	" "
Asphalt	0.47 to 4.10	" "
Paraffin	1.63 to 9.21	" "
Sulphur	0.41 to 1.42	" "
Nitrogen	0.887 to 2.198	" "

He remarks that "the large percentage of nitrogen may be greatly lessened in commercial practice, in which steam will probably be injected into the retorts during the distillation."

In Bulletin 641-F. of the U. S. G. S., Dean E. Winchester gives the following results of distillation with and without steam:

"During May, 1916, six samples of oil shale were tested at the Bureau of Mines, with an apparatus similar to that used in the field, but so ar-

ranged that superheated steam was injected into the retort during the entire process of distillation. The samples were selected to represent a wide geographical distribution, as well as differences in richness and physical character, and the results of the tests are extremely interesting. Each of the samples had been tested previously in the field apparatus without steam, and the results, therefore, furnished factors that may be used to convert the results of field tests into what are very probably close approximations to results to be expected from commercial practice.

Comparison of Dry and Steam Distillation

COMPARISON OF STEAM AND DRY DISTILLATION

Sample No.	Oil				Ammonium Sulphate		
	With Steam		Without Steam		Theoretical yield, equivalent of nitrogen in shale (pounds per ton)	Yield as determined	
	Yield (gallons per ton)	Specific gravity	Yield (gallons per ton	Specific gravity		With steam (lb. per ton)	Without steam (lb. per ton)
4..	23.0	0.9346 (19.7°B.)	16.8	0.8937 (26.6°B.)	36.6	13.4	3.5
27..	10.0	.9135 (23.2°B.)	8.4	.8946 (26.5°B.)	43.2	29.9	18.3
32..	44.0	.9630 (15.3°B.)	40.6	.8838 (28.4°B.)	50.8	34.0	8.5
51..	39.0	.9234 (21.6°B.)	28.0	.9126 (23.4°B.)	43.2	15.8	7.3
66..	55.0	.9286 (20.7°B.)	55.0	.9052 (24.6°B.)	75.4	23.1	9.6
132..	50.0	.9109 (23.7°B.)	50.0	.8449 (35.7°B.)	80.1	8.4	4.5

The average amount of ammonium sulphate produced from the shale by steam distillation was about two and one-half times the amount obtained from the same samples by dry distillation, thus providing a factor for the conversion of the figure

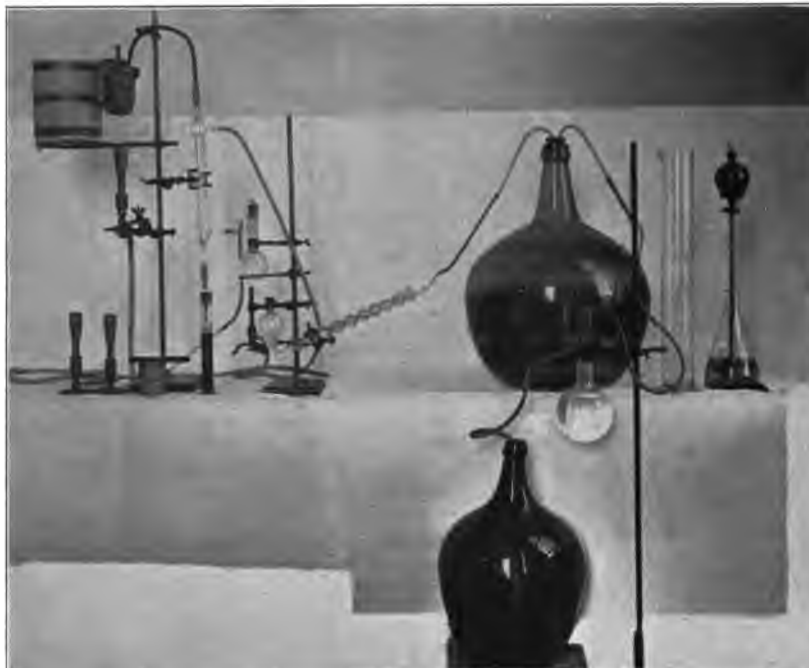
for ammonium sulphate by dry distillation to ammonium sulphate which may be obtained with steam distillation—the method practiced in the oil shale industry in Scotland and France.

Methods for the Proximate Analysis of Oil Shale and Shale Oil Used in the Chemical Laboratories of the Colorado School of Mines

The yield of oil, ammonia, permanent gases, and spent shale from an oil shale may be determined in from three to five hours by the following method. A weighed sample of the shale is distilled dry from an iron retort. The oil and water produced are condensed and measured by volume. The permanent gases evolved are bubbled through a solution of sulphuric acid to remove ammonia and then collected over water and measured. The water distilling from the shale contains part of the ammonia and is separated from the oil and added to the acid solution. The oil, condenser, cylinder, and glass connecting tubes are rinsed until free from ammonium compounds and the rinsings also added to the solution of sulphuric acid. This solution is then neutralized with sodium hydroxide and the ammonium sulphate in the neutral solution changed to sulphuric acid and hexamethylenetetramine by warming with formaldehyde. The acid formed is equivalent to the amount of ammonia and is titrated with a standard base solution. The spent shale remaining in the retort is removed and weighed.

Solutions used. Sulphuric acid, approximately one-normal; standard fifth-normal sodium hydrox-

MOUNT LOGAN. COLORADO



APPARATUS FOR OIL SHALE ANALYSIS, OIL SHALE LABORATORY, COLORADO SCHOOL OF MINES. GOLDEN, COLORADO

ide; neutral forty per cent formaldehyde; one per cent phenolphthalein and solutions of litmus or cochineal.

Apparatus used. Three Scimatco burners, size 4; one Bunsen burner; one 0.50 pint cast iron retort, with cover, clamp and iron delivery tube 14 inches long, bent in a semicircle; one burner-guard made of magnesia steam-pipe insulation, 8 inches long, 4.50 inches inside diameter and one inch thick; one 10-inch condenser with straight inner tube; one 100-cc. graduated cylinder; one 100-cc. distilling flask; one Meyer absorption tube; one carboy; one 1000-cc. distilling flask; one 25 to 50 liter bottle; one 1000-cc. graduated cylinder; one 800-cc. conical flask; one 250-cc. separatory funnel; one burette; spatula; pliers; rubber stoppers; rings, clamps and ringstands for supporting the apparatus; rubber and glass tubing for connecting apparatus, water and gas; asbestos board for covering the retort.

Arrangement of apparatus. The apparatus is connected and set up as shown in the accompanying plate. The junction surfaces between the retort and cover must be clean, smooth and fit closely. The inner tube of the condenser has about the same diameter as the iron delivery tube from the retort. The ends of these tubes are in contact and are joined with new heavy walled rubber tubing. The other end of the condenser is connected in a similar manner with a glass adapting-tube which extends through the stopper and about three

inches into the 100-cc. cylinder. The jacket of the condenser is connected with a 100-cc. distilling flask in such a manner that the water flowing to the condenser may be heated when necessary to remove heavy oils from the condenser. The Meyer tube is connected in between the cylinder and the carboy. The tube leading into the carboy extends just through the stopper and the tube leading out extends from the bottom of the carboy to the bottom of the 1000-cc. distilling flask. This last tube is filled with water and about 18 inches of its length consists of rubber tubing. The flow of water from the distilling flask is aided by bending downward the last few inches of the side tube. The carboy and the distilling flask are filled with water and cooled to room temperature before the distillation is started. The distilling flask at first is elevated so that the level of the water in it and the carboy is the same.

Distillation of the shale. Two hundred and forty-one grams (eight and one-half ounces) of the shale are placed in the retort. If the shale is high grade 219.1 grams are used and the yield in each case increased by one-tenth so as to rate it all on the basis of 241 grams and facilitate calculation. A thick paste is made by mixing "Smooth On" cement (Engineer's "Smooth On," No. 1) with a little water. Using a spatula this paste is quickly and evenly spread on the junction surfaces of the lid and retort. The lid is placed on at once and the clamp firmly screwed down with the pliers.

Cement is then pressed into the groove between the retort and lid. The retort is now placed in position for the distillation and covered by the magnesia burner-guard. About 20 cc. of approximately one-normal sulphuric acid are placed in the Meyer tube and the connections adjusted so as to be gas tight. The 1000-cc. distilling flask is lowered about one foot. This siphons some water from the carboy and diminishes the pressure in the apparatus. If air continues to bubble through the Meyer tube it indicates a leak somewhere. When the leak is in the retort, the cement is removed and fresh cement put on. There are few leaks of this kind when the cement is allowed to set 15 to 30 minutes before testing. When the apparatus is ready for the distillation a gentle flow of water is started through the 100-cc. distilling flask and the outer tube of the condenser. The 1000-cc. distilling flask is raised until the level of the water in it is about 8 inches lower than that in the carboy. This difference of level lessens the tendency to leak and is maintained throughout the distillation. Small pieces of asbestos board are placed over the top of the burner-guard so as to cover about two-thirds of the retort on the side farthest from the condenser. In this way the iron delivery tube is kept warm and condensation at this point is minimized. The retort is heated slowly in order to drive off the oil at as low a temperature as possible. A Scimatco burner is adjusted to produce a flame four inches high and

the burner placed for thirty minutes with the top four inches from the bottom of the retort. The burner is then raised one inch and the heating continued for half an hour, when the burner is raised another inch and the heating continued for another half hour. The burner is now raised until the top is one-half inch from the retort. After thirty minutes a second Scimatco burner is added and in another half hour a third burner is introduced. The heating is continued with the three burners one-half inch from the retort until gas is no longer evolved from the shale. About ten minutes before this time the flow of water through the condenser is shut off, a flame placed under the 100-cc. distilling flask and the water heated almost to boiling. The water is then turned on slightly and the condenser kept hot until all the oil has melted and drained from the condenser. The number of cubic centimeters of oil and water in the cylinder is carefully noted. Each cubic centimeter represents one gallon of oil or water per ton of shale when 241 grams are used for the distillation. The volume of water flowing from the carboy is equal to the volume of permanent gases. This volume in cubic centimeters times 0.1337 is equal to the yield of permanent gases in cubic feet per ton of shale when 241 grams of shale are taken for the distillation. After the retort has cooled somewhat the spent shale is removed and weighed. The number of grams of spent shale obtained from 241 grams of shale mul-

tiplied by 8.3 equals the number of pounds of spent shale per ton of shale.

Determination of ammonia. The oil and water in the cylinder are transferred to the separatory funnel. The water is separated and run into an 800-cc. conical flask. The acid solution is poured from the Meyer tube into the conical flask. Then the Meyer tube is rinsed with 50 cc. of hot water. This water is poured through the inner tube of the condenser and the adapting-tube into the cylinder. It is transferred from the cylinder to the oil in the separatory funnel. The oil and hot water are shaken up together. The water is then run into the 800-cc. conical flask, and the rinsing in this manner with 50-cc. portions of hot water repeated three more times, adding all the rinse water to the conical flask. The small tube connecting the cylinder and Meyer tube is also rinsed into the conical flask three times with hot water. The acid solution in the conical flask now contains the ammonia as ammonium sulphate. This solution is boiled to remove carbon dioxide and then sufficient litmus or cochineal solution is added to produce a distinct color. Sodium hydroxide is added from a burette until the solution is just neutral. If in doubt about the end-point or if the end-point has been passed a few drops of sulphuric acid are added and the end-point again determined. It is best to take the end-point where the indicator begins to change, that is when the litmus turns to a red-violet color rather than the final change to a deep blue. Ten

cc. of neutral 40 per cent formaldehyde are added to the solution and the solution boiled for about one minute. The following reaction takes place:

$$6HCHO + 2(NH_4)_2SO_4 = (CH_2)_6N_4 + 2H_2SO_4 + 6H_2O$$

The solution is cooled to about 60°C, phenolphthalein added and the sulphuric acid formed titrated with the standard sodium hydroxide. Each cubic centimeter of fifth-normal sodium hydroxide is equivalent to 0.10954 pound of ammonium sulphate per ton of shale when 241 grams are used for the distillation.

Plant control tests. The analytical distillation of shale by the above method gives the maximum yield of ammonia and permanent gases by dry distillation. For control work in plants, where the object in retorting is to obtain a maximum yield of the best oil rather than the largest amount of ammonia or permanent gases, the method may be considerably shortened in time and the laboratory distillation made more nearly like that of the plant by stopping the distillation as soon as the oil has all distilled off. The yield of ammonia and permanent gases are then much diminished but more nearly approach the amounts obtained in plant operations by dry retorting. For control work in plants retorting with steam the following modification is made in the laboratory distillation. The 100-cc. cylinder is replaced by a liter suction flask containing 100 cc. of approximately one-normal sulphuric acid. The adapting tube extends

to the bottom of this flask. The retort is drilled and threaded near the bottom, and an iron tube similar to the delivery tube introduced. This tube is fitted with a stop-cock and connected with a suitable source of steam. After the shale in the retort has been heated to 212°F, steam is introduced and continued at a rate corresponding to the quantities used in the plant operation. When the oil has all distilled out the distillation is discontinued, the oil and acid solution from the flask are separated in a large separatory funnel, the oil is rinsed in the usual way and the rinsings together with the acid solution and the acid from the Meyer tube placed in a graduated flask. The ammonia is then determined in an aliquot portion of this solution.

The specific gravity of the shale oil is determined with a small sized Tagliabue Baumé hydrometer. The oil is placed in a 50-cc. cylinder and the hydrometer lowered carefully to avoid getting the oil on the hydrometer higher up than it will finally sink in the oil. The temperature of the oil is taken and correction is made when the oil is not at 60°F.

Analytical distillation of shale oil. Determining the most desirable conditions for the analytical distillation of shale oil is a difficult problem. In distilling off the heavier half of a shale oil a large amount of what appears to be cracking occurs. Gasoline fractions form continuously without much elevation of the temperature unless the dis-

tillation is forced by application of greater heat. Whether this is due more to cracking or to a depolymerization of certain naphthenes or other compounds has not been fully determined. A simple distillation of the oil does not well indicate what the oil consists of nor adequately show what may be produced from it. The amount of crude shale oil used, the rate of the distillation, and the form and size of the distilling flask are all factors which have considerable influence on the amount and properties of the oil obtained in the different distillates. Pending further investigations of the analytical distillation of shale oil the following method is used and recommended. One hundred cubic centimeters of the shale oil are distilled from a standard 100-cc. Engler flask. The flask is supported in an upright position on a ring of asbestos having a circular hole 1.25 inches in diameter. Heat is applied by a Bunsen burner to that portion of the flask in the hole. The thermometer used is graduated for total immersion and registers to 800°F. The bulb is placed opposite but slightly lower than the junction of the side tube and the thermometer is supported by a cork stopper in the flask. The end of the side tube from the flask is bent downward and joined to the vertical condenser by a cork stopper. A ten-inch condenser with a straight inner tube is used. The distillate is received in 10-cc. graduated cylinders. The oil is heated slowly at first until all the water has distilled out. The burner during most of the

distillation is manipulated in the hand, the thermometer is carefully watched, and the rate of distillation limited to 2 to 2.5 cc. per minute. This is about one drop per second. The number of cubic centimeters of water distilling off and the temperature when the first drop of oil reaches the graduate are noted and recorded. A record is kept of the temperature at the end of each 10-cc. fraction. The amount of oil distilling off below 410°F is noted and recorded as crude gasoline. These fractions are united and placed in a 25-cc. cylinder. The fractions coming off between 410°F and 572°F are united, measured, and recorded as crude illuminating oil. Usually the fraction above 572°F is not distilled but measured by difference and recorded as heavy oil. This portion is poured while hot into the original 100-cc. cylinder. The gravity of the gasoline, illuminating oil, and heavy oil fractions is taken with a small hydrometer in a 25-cc. cylinder or a test-tube. When the quantities of oil are very small a pycnometer is used. The three fractions are then united in the 100-cc. cylinder, mixed well, and the gravity taken. The loss in gravity is calculated by subtracting this from the gravity of the crude oil taken before the distillation. The separation into the three fractions does not interfere with recording the temperature for each 10-cc. portion coming from the condenser. When desired the distillation is continued until a dry coke is left in the flask. The fractions above

572°F are united and measured as heavy oil and the coke determined by difference. When it is convenient or desirable the distillation may be made on a 300 or a 500 cc. sample, using a flask with a Hempel column similar to that recommended by the United States Bureau of Mines (Bulletin 125) for the analytical distillation of crude petroleum. Cuts of 30 or 50 cc. are taken.

Tests Made at the Colorado School of Mines

For the past three years much interest in the industry has been taken at the Colorado School of Mines. Courses of instruction in oil shale analysis and petroleum refining have been offered to the regular students. Series of popular lectures have been offered to the public. Hundreds of preliminary oil shale analyses have been made for the residents of Colorado, of which the following of Colorado shales are typical:

F. A. Wadleigh, Denver, Colorado.

No. 1
Oil ....65.50 gal. a ton

DISTRIBUTION

Oil distilled at 150°C, 8.00 gal.
Oil distilled at 200°C, 3.50 gal.
Oil distilled at 250°C, 8.50 gal.
Oil distilled at 300°C, 9.00 gal.
Oil distilled above 300°C, 42.60 gal.
Total, 65.50 gal. a ton.

No. 2

Oil ....77.60 gal. a ton

DISTRIBUTION

Oil distilled at 150°C, 12.00 gal.
Oil distilled at 200°C, 7.00 gal.
Oil distilled at 250°C, 6.00 gal.
Oil distilled at 300°C, 10.00 gal.
Oil distilled above 300°C, 42.60 gal.
Total, 77.60 gal. a ton.

No. 3

Oil ....30.00 gal. a ton

DISTRIBUTION

Oil distilled at 150°C, 5.6 gal.
Oil distilled at 200°C, 3.2 gal.
Oil distilled at 250°C, 7.2 gal.
Total oil, 30.00 gal. a ton.

Joseph Bellis, Grand Valley, Colorado:

No. 1

Oil ....75.0 gal. a ton

DISTRIBUTION

Distilled at 150°C, 14.40 gal.
Distilled at 200°C, 2.40 gal.
Distilled at 250°C, 12.00 gal.
Distilled at 300°C, 16.80 gal.
Distilled above 300°C, 29.40 gal.
Total, 75.00 gal. a ton.

Joseph Bellis, Grand Valley, Colorado:

No. 2

Oil ....60.00 gal. a ton

DISTRIBUTION

Distilled at 150°C, 14.00 gal.
Distilled at 200°C, 6.00 gal.
Distilled at 250°C, 3.40 gal.
Distilled at 300°C, 7.80 gal.
Distilled above 300°C, 28.80 gal.
Total, 60.00 gal. a ton.

General Investigations

The Colorado School of Mines offers the general facilities of its Department of Metallurgical Research to oil shale investigators. Experimenters may erect their retort at their own expense, and may make use of the general conveniences and equipment of the plant. On completion of their work and when they feel that their retort will operate satisfactorily the Department will make an impartial test run and give an official report of the results obtained. Three companies have already signified their intention of accepting this offer and erecting their retorts. In this Department, A. J. Franks, a Fellow in Chemistry, is investigating the effect of physical decomposition products of the carbonization of oil shale.

In the chemical laboratories of the Colorado School of Mines research work has been undertaken in order to secure a general knowledge of the

composition of oil shale and its products, and to show the variation in the composition of the oil shales of Colorado, Utah, Wyoming, and Nevada, in order that it may serve as a basis for comparison in rating the value of any individual sample. Data from all available sources have been investigated, and although they show the composition of the oil shale in only about fifty localities in each State, yet they are of considerable value in estimating the composition of the same strata in other localities where the shale has not yet been reached, because the oil in the shale is fixed and not migratory like petroleum. Differences in laboratory methods of distillation and in the form of apparatus used cause the analyses of oil shales to vary more than any other substance analyzed by the chemist. Until some standard method and type of apparatus is generally adopted by analysts, the results of their analyses must not be interpreted too rigidly. Allowance must also be made for the fact that commercial plant distillation must necessarily vary from that done with small retorts in the laboratory.

Chemical Investigations

The following figures are based on the results of one hundred thirty-two analyses published by the United States Geological Survey, fifty-two analyses made in the chemical laboratory of the Colorado School of Mines, and thirty-seven from other sources. Sixty-four of the analyses were on Colorado shales; fifty-six on Utah shales; forty-

five on Wyoming shales, and fifty-six on Nevada shales.

No. of Analyses	Constituent	Unit	Minimum	Average	Maximum
221	Shale oil	Gal. per ton	.30	38.0	90.0
221	Shale oil	Spec. gravity	0.832	0.890	0.950
179	Ammonium sulphate ..	lb. per ton	0.40	9.4	20.0
74	Gas.........	cu. ft. per ton	400.0	4000.0	8300.0
36	Water.......	Gal. per ton	1.0	4.8	8.5
36	Spent shale ..	lb. per ton	900.0	1200.0	1800.0
36	Sulphur.....	Per cent	0.25	0.80	5.20
16	Heating value	B.t.u.	1000.0	4500.0	8000.0
8	Carbon......	Per cent	0.83	22.5	37.2

Shale distillations with steam yield a few more gallons of oil a ton than dry distillations and the specific gravity of the oil is between .03 and .04 greater. Steam distillations also increase the quantity of ammonium sulphate. The values given in the table above were obtained by dry distillation. In the laboratory distillations the yield of gas is almost doubled if the retort is surrounded by magnesia insulation and the final temperature is thus increased a few hundred degrees.

Shale oils vary considerably in color, specific gravity, and viscosity, and in their content of sulphur, asphalt, and paraffin. As ordinarily produced, they usually contain a larger percentage of unsaturated hydrocarbons than well petroleum. Experiments in cracking the heavier distillates from shale oil show that these oils crack very

easily. One sample of oil obtained as a cut between 585°F and 620°F with a gravity of 27°Baumé, when distilled with steam gave 18 per cent gasoline, 60°Baumé; 35 per cent kerosene, 47° Baumé; 25 per cent lubricating oil, 25°Baumé; and left a heavy residue of 30 per cent. The following summary is made from data obtained by analysis and distillation of twenty-four different samples of crude shale oil. Nine of these were analyzed by the United States Bureau of Mines and the others in the chemical laboratories of the Colorado School of Mines.

	Specific Gravity	Minimum	Average	Maximum
Initial boiling point		50° C.	65° C.	80° C.
Gasoline, to 150° C.	.750–.850	5%	11.7%	20%
Kerosene, to 300° C.	.820–.900	25%	38%	52%
Heavy oil, residue	.900–1.02	30%	45%	63%
Unsaturated hydrocarbons in kerosene		50%	63%	75%
Unsaturated hydrocarbons in crude shale oil		30%	60%	90%
Asphalt in crude shale oil		.35%	2.5%	4.5%
Paraffin in crude shale oil		1.00%	5.0%	9.5%
Sulphur in crude shale oil		.3%	.75%	1.5%
Nitrogen in crude shale oil		.75%	1.2%	2.2%

Black Shales

G. H. Ashley in U. S. G. S. Bulletin 641 has reported on the black shales in the eastern States. The average of his tests by States is as follows:

State	No. of Samples tested	Average Yield Gal. of oil to the ton
West Virginia..................	5	1.40
Tennessee......................	13	5.20
Pennsylvania...................	7	27.60
Ohio...........................	4	7.10
Kentucky.......................	3	5.10
Illinois.......................	2	14.00
Indiana........................	7	10.00

He adds an estimate that the oil shale deposits in southeastern Indiana contain 100,000,000,000 barrels of oil.

Refining Tests

Crude shale oil from the Elko, Nevada, shales refined by the Wells Process is reported by W. W. Strickler, Tulsa, Oklahoma, to give the following results:

Baumé gravity of the crude 23.2
23 per cent gasoline of 460 end point
46 per cent automobile oil 225 vis. at 70
6 per cent slack wax of 130.5 melting point (unsweated)
10 per cent asphaltic residue with melting point of 160/170

J. B. Jones, Petroleum Engineer, Kansas City, Missouri, reports the following results of refining crude shale oil from Parachute creek, Colorado, by the Wells Process:

15 per cent Straight run gasoline, 460 end point

26 per cent Gas oil (naphtha, benzine, kerosene, to be put through cracking process and produce 13 per cent gasoline, 3 per cent fuel, 10 per cent loss)
43 per cent Motor oil—viscosity 225 at 70 degrees
6 per cent Paraffin wax, unsweated, 130 melting point
8 per cent Asphaltic residue
2 per cent Loss

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100 per cent

A refining test of Nevada crude shale oil by the Wells Oil Refining Process Company, Columbus, Ohio, gave the following:

		GALS. PER BBL.
Gasoline (460 end point)	23%	9.66
Automobile Oil (225 viscosity at 70°)	46%	19.32
Slack (130.5 melting point unsweated)	6%	2.32
Asphaltic residue (Melting point 160-170°)	10%	4.20
Loss	15%	

The report adds: "This crude requires rather careful handling, but by our methods these results can be duplicated day after day, and the resulting

products are better in percentages and quality than are obtainable from many of the high priced crudes."

Grand Valley oil shale giving 78 gallons to the ton refined by the Wells Oil Refining Process at Columbus, Ohio, October 7, 1918, gave:

Straight run gasoline	19 per cent
Lubricating oil	60 per cent
Intermediate or gas oil	10 per cent
Asphaltic residue	5 per cent
Paraffin wax	2 per cent
Refining loss	4 per cent
	100 per cent

The gasoline was of 460 end point.

The lubricating oil was 395 flash—475 fire.

Viscosity 410 at 100 degrees.

The Wells Refining Company, of Columbus, Ohio, reports on a sample of crude shale oil from Grand Valley, Colorado, as follows:

19 per cent gasoline, 460 end point
12 per cent gas oil
60 per cent lubricating oil, 395-flash 475-fire 410 vis. at 100°
5 per cent asphaltic residue
2 per cent wax
2 per cent loss

100 per cent

A refining test of crude shale oil, distilled from Colorado shale, made at the Cosden and Company refinery, Tulsa, Oklahoma, gave the following:

Gasoline	15%
Naphtha, benzine, and kerosene	26%
High grade lubricating oil	43%
Paraffin wax (melting point 135°)	8 to 10%

By cracking the naphtha, benzine, and kerosene an additional 13 per cent of gasoline was obtained, making a total of 28 per cent of gasoline, and 5 per cent fuel oil. End point in the operation was 460 degrees. The loss was 16 per cent.

As a result of many experiments it is estimated that a complete refinery can, if working efficiently, give the following average results on crude shale oil:

Gasoline	25 per cent
Lubricating oil	60 per cent
Paraffin wax	2 per cent
Kerosene or fuel oil	3 per cent
Asphaltic residue	7 per cent
Loss	3 per cent
	100 per cent

In addition to these products, there will be the ammonium sulphate ranging from 20 to 30 pounds to the ton of shale, and about 2,500, or more, cubic feet of gas, from which can be extracted from two to three gallons of gasoline per 1,000 cubic feet of

gas, with sufficient high grade hydrogen gas left over for fuel requirements in operating the retort and refinery plants.

De-Polymerization

G. W. Wallace, in an article on "New Lines of Thought on the Recovery of Oil from Bituminous Substances," cites a test made on a heavy shale oil distillate of a gravity of 20° Baumé. This was redistilled in the ordinary manner of dry distillation. The finished distillate amounted to 99 per cent of the original oil and had a gravity of 27.9° Baumé, or 7.9° Baumé lighter than at the outset. These figures indicate that there could have been practically no cracking, as ordinarily understood. Ordinary cracking is inevitably accompanied by a separation of carbon and a production of non-condensible gas. Neither of these phenomena could have taken place in this instance to any marked extent, as shown by the high percentage of recovery. This case is typical of what is continually being observed by experimenters. A. J. Franks, Fellow in Chemistry, Colorado School of Mines, has offered the suggestion, or hypothesis, that the phenomenon may be due to de-polymerization, whereby saturated molecules of high molecular weight are split into unsaturated compounds of less molecular weight. This would necessitate no separation of carbon or gas. In specific cases gases might be formed, of course, if any of the de-polymerized products happened to be of a gaseous nature, but this is not a necessary adjunct of

the de-polymerization. This hypothesis would fully account for the results observed.

After all laboratory experiments are made and all theoretical considerations are given due weight, the crux of the whole situation lies in the construction and operation of a commercial sized retort that will produce the maximum of good shale oil under commercial conditions.

CHAPTER VII

ECONOMIC FACTORS

Investment Value and Income

If a company were going into the production of crude petroleum in the Mid-Continent field and were to purchase outright their oil production to-day, it would require, to secure a production of 500 barrels of crude oil daily, with reasonable territory in reserve, an investment of not less than one million dollars. This production will constantly grow less and at the end of one year will be considerably less, if a large amount is not invested in new drilling. At least fifty per cent of income must be set aside for operating, drilling, and maintaining production, leaving but fifty per cent of income for dividends or surplus. Besides, in this case the company will not own or operate a refinery and has to take the price paid by the pipe lines for crude oil. If a like amount is invested in the shale oil industry, lands may be acquired with sufficient supply for 100 years or more of raw material for the production of 500 barrels and upwards daily of crude oil. The concern can equip, operate, and own a complete reduction works and refinery and thereby obtain the wholesale market value of

refined oils for a permanent industry, with a capacity and output of 500 barrels or more daily. The value of the refined products may be from three to four times the value of crude oil. The complete cost for building and equipping a shale plant will run from $1,000 to $2,000 per ton of shale handled accordingly as it is equipped and the complete or incomplete finishing work done on the oils and by-products. A skimming or cracking plant can be built at first to make good returns, but it is advisable when possible to build more complete works, equipped for paraffin wax and lubricating oils, for this will greatly enhance the profits.

Shale Oil and Well Oil per Square Mile

In 1915 the area of proved oil land in the United States was 4,109 square miles. The total production of oil up to that time was 3,617,000,000 barrels and the estimated amount remaining underground was 5,753,000,000 barrels. Hence the total production of oil from the 4,109 square miles of proven ground would be 9,370,000,000 barrels or 2,280,360 barrels to the square mile. One ten-foot seam of oil shale, yielding one barrel of oil to the ton, will give 15,488,000 barrels of oil or seven times as much oil to the square mile as is obtained from well oil. In Colorado, Utah, and Wyoming the thickness of the shale beds runs far above 10 feet, but figuring on this absurdly low thickness it is evident that the production of oil from shale to

the square mile will be many times that of well oil to the square mile. However, to delve a little into figures, oil shales of commercial value in our western States are frequently a hundred or more feet thick, so situated as to be broken and run into a retort at a very low cost. In Parachute creek are three seams averaging at least ten feet in thickness traceable in bluffs for sixty-nine miles in and out of Parachute creek and its tributaries. Take this as a basis because it is plainly visible to the layman. Since there are available 15,488,000 barrels of oil to the square mile in a ten-foot seam, in these three seams there would be available 46,464,000 barrels of oil to the square mile. In Colorado and Utah there are 5,500 square miles of accessible oil shale capable of producing the enormous amount of 255,552,000,000 barrels of oil or 27 times the total past and future production from the 4,109 square miles of proven oil ground in the entire United States. These figures are certainly startling; but so are all other fundamental statements about the possibilities of the oil shale industry.

Value of Oil Shale Land

At the present time virtually all available shale deposits on Government land have been filed upon as placer. They are generally taken up in association claims, i. e., in eight twenty-acre contiguous tracts by eight locators. Each locator has a one-eighth undivided interest in the 160 acres. Annual assessment work

to the extent of $100 must be done on the tract to hold the title. The intrinsic value of a particular tract may be much or little. If it is situated far from a railroad, beyond even a wagon road, and without water, it is virtually without present market value. If it is accessible, near to transportation, with an available water supply, with natural benches for retorts and ample dumping ground, and the rich shale beds are thick and easy to get at, then the land may have a present value of from $25.00 to $50.00 an acre and a prospective value in the hundreds of dollars an acre.

Location of Oil Shale Claims

The statute of 1897 says: "Any person authorized to enter lands under the mining laws of the United States may enter and obtain patent to lands containing petroleum or other mineral oils, and chiefly valuable therefor, under the provisions of the laws relating to placer mineral claims." The location of oil lands as placers was general until 1896, when the Secretary of the Interior ruled adversely. Thereupon Congress, in 1897, passed a law re-establishing the former practice. The higher courts as yet have had no opportunity to pass upon the validity of title to oil shale land located under the placer law.

The well known case of Webb. vs. the American Asphaltum Co. furnishes the nearest parallel case. In the Circuit Court of Appeals, Eighth District, it was held that asphaltum, when it is in solid form

and is found as a vein or lode, should be located as a lode. At the present time no court decision has been rendered which involves specifically the point as to how oil shale lands shall be located; that is, whether as lode or as placer. It would seem, however, that from the peculiar formation of oil shale deposits they should be located as placers. As generally found in Colorado, Utah, and Wyoming, these deposits are virtually horizontal and cannot be said to have apexes within the sense that miners and the Mining Act of 1872 contemplate. Neither can horizontal oil shales be said to be *in place* in the sense that we find deposits of other valuable minerals *in place* when found in lode, vein or ledge formation. The shale deposits cannot even be said to have a clearly defined hanging wall, such as is contemplated by the statute, since they are not covered by a non-mineral bearing country rock such as the miner is accustomed to find as constituting his overhanging wall, but he finds merely an earthy deposit such as is generally found in the ordinary gold placer.

Dividends, Scotland

Dividends paid by the three large Scotch oil-shale companies for a period of years are as shown on page 121.

In 1882 the net profit on each ton of shale treated in Scotland was, on the average, 89 cents. In 1897 the profit was 50 cents. In 1909 the cost of mining and manufacturing was $2.06 a ton and the net profit 83 cents a ton.

OIL SHALE. UTAH

A MOUNTAIN OF OIL SHALE. COLORADO

	Broxburn Capital, $1,675,000 %	Oakbank Capital, $1,500,000 %	Pumpherston Capital, $1,650,000 %
1895–1896	7½	5	
1896–1897	7½	0	
1897–1898	7½	0	
1898–1899	8½	5	
1899–1900	15	7½	20
1900–1901	20	12½	15
1901–1902	15	7½	7½
1902–1903	15	7½	20
1903–1904	15	12½	30
1904–1905	15	15	30
1905–1906	15	15	30
1906–1907	15	15	50
1912–1913	10	15	35
1913–1914	10	15	25
1914–1915			10
1915–1916	7½	10	25

The present financial condition of the four leading Scotch oil shale companies may be seen from the following figures taken from their official reports for 1917-18:

			Dividends
The Pumpherston Oil Company, Ltd.	First Preference Shares	$500,000	6%
	Second " "	250,000	6%
	Ordinary " "	1,500,000	40%
Young's Paraffin Light and Mineral Oil Company, Ltd.	Ordinary Shares	$3,500,000	5%
The Oakbank Oil Company, Ltd.	Preference Shares	$500,000	6%
	Ordinary "	1,000,000	15%
The Broxburn Oil Company, Ltd.	Preference Shares	$500,000	6%
	Ordinary "	1,000,000	15%

To estimate the cost of production of crude shale oil is not easy, since the economic factors in different localities vary greatly and there is not as yet any full-sized plant in operation from which exact data can be obtained. A careful study of the cost of mining coal under similar conditions and an estimate of the cost of retorting results in the following figures, which are based on underground mining and are necessarily higher than the cost of open cut work. It seems that in no property likely to be opened in the near future will these costs be exceeded. They are based on a plant of 400 tons daily capacity, treating shale that produces a barrel of oil to the ton.

Estimated Cost of Mining and Retorting

	COST PER TON
Mining	$1.25
Breaking	.10
Retorting	.35
Loading and shipping	.05
Amortization, interest, and overhead expenses	.10
Estimated cost of producing a ton of crude shale oil	$1.85

These costs for mining and retorting are estimated on the basis of 42 gallons to the ton of shale, but there are several available, workable strata at Watson, Utah, and in the Parachute Valley, Colo., that will produce from 50 to 100 per

cent more. Consequently, in practice, these costs per barrel of crude oil produced may be considerably reduced.

Estimated Cost of Mining, Retorting, and Refining

The following estimate of the mining, retorting, and refining is also based upon oil shale producing a barrel of shale oil (42 gallons) to the ton of shale in a plant treating 400 tons a day.

	COST PER TON
Mining	$1.25
Breaking	.10
Retorting	.35
Refining by the Wells Process	.42
Piping, loading and shipping	.10
Amortization of plant equipment	.05
Interest on investment	.05
Overhead expenses	.25
	$2.57

The cost of a distillation plant, with all accessories, of a capacity of 100 tons of shale a day is estimated at from $65,000 to $100,000, according to local conditions. If proper plans were made in advance for enlargement, additional units could be erected at about one-half the cost of the original unit. The cost of a Wells refining plant with a daily capacity of 400 barrels, to include a sulphate of ammonium and gasoline absorption plant, would cost from $300,000 to $350,000, according to local conditions. All estimates of plant equipment and

Estimated Cost of Distillation and Refining Plants

operation should be regarded as distinctly tentative.

The first investigators of oil shale deposits, ten years ago, were well satisfied that the shale could be made to produce oil in large quantity and that the deposits of shale were of enormous extent. With well production ample to supply all demands, Pennsylvania crude selling around $1.35 a barrel, and Mid-Continent crude around forty cents a barrel, they were justified in their conclusion that there was no justification for an oil shale industry. However, since that time the demand has increased, the supply has not kept pace, the price of crude has mounted to a price above the cost of producing shale oil and the entire economic conditions have changed. Consequently, the time has come for oil to be produced from shale on a commercial basis and at a profit.

Shale Versus Well Oil

Crude shale oil, when produced, will naturally first come into competition with the Wyoming and Mid-Continental oils. Since the estimate of $1.85 is conservatively high, the lowest competitive price, $2.50 (in the Wyoming field), and the highest price, $3.50 (in the Mid-Continental field), are both well above the danger line. If, then, oil shale retorting plants were now in effective operation on a commercial scale there is little doubt that their product would find a ready market at a remunerative price. There is, too, every reason to believe that the price of oil has only begun its upward course

and much higher prices will soon be reached. Nor will the price of crude oil alone remain high. On account of the present large foreign demand, in addition to the strong domestic demand, the prices of lubricating oils and kerosene will very likely first be affected by the advance in crude oil. The shortage in the supply of gasoline is an additional factor which will help to advance the price also. Other refinery products are also due for an advance. All of which will aid materially in placing the oil shale industry on a profitable basis.

The recent coal strike has brought home to the large consumers of coal the danger of depending solely upon coal for fuel. Already many of the large New York and New England manufacturing plants as well as larger office buildings are changing to oil. Many ocean steamships, as well as those on the Great Lakes, are also changing. In Chicago all the public school buildings, in units of ten at a time, are being changed to use oil for fuel. On railroads fuel oil is fast coming into favor on account of the low labor cost, the conveniences, and the high efficiency. The following railroads now use fuel oil over all or a considerable part of their lines: Atchison, Topeka & Santa Fe, Southern Pacific, Kansas City Southern, Western Pacific, Northwestern & Pacific, Florida East Coast, Chicago, Milwaukee & St. Paul, Great Northern, Oregon Short Line, Texas & Pacific, Chicago, Burlington & Quincy, Chicago & Northwestern, El Paso Southwestern, Delaware & Hud-

son (Adirondack Division), New York Central (Adirondack Division), Oregon-Washington Navigation Co., Texas Railways, Missouri, Kansas & Texas.

Economic Conditions, Jan., 1918

As early as January, 1918, "Petroleum" said editorially, "California crude stock is the lowest in years. Reduction of crude oil stocks in California to slightly less than 34,000,000 barrels, the smallest in more than six and one-half years, emphasizes the strength of the oil situation on the Pacific Coast. Several million barrels are regarded as unavailable for use, so actual surplus is smaller than appears. Consumption of crude oil by Pacific Coast refineries has been exceeding production at the rate of about 1,000,000 barrels a month the last year or so. In twenty-two months California stocks of oil in storage and above ground have been depleted by over 23,000,000 barrels."

Senator Phelan in the Congressional Record of July 29, 1919, said: "The Director of the Bureau of Mines would like to emphasize the fact that there is no other situation in respect to future supplies of essential raw materials for the United States and in respect to our future trade, which is at the present time so important and so critical as the petroleum situation. In so far as America is concerned, the whole complexion of our petroleum industry has changed within the last two years. We are now consuming more crude oil than we produce, depending upon imports to make up the

deficit. Forty per cent of our natural petroleum reserves has been taken out of the ground and used, whereas we have used up about one per cent of our coal. Our nationals have not gone abroad to any extent. American oil producing companies are to be found only in Mexico, Central and South America, and Roumania. The United States produces yearly 65 to 70 per cent of the world's total production. The increase of our consumption of crude oil in 1918 over the consumption in 1911 was 190,000,000 barrels. We are eating up our substance. In view of the extensive use of fuel oil in the industries, merchant marine, and navy, lubricating oils and gasoline, it seems certain that our consumption of crude oil will continue to increase at a rate comparable with that of the past. Our consumption in 1918 was 406,916,000 barrels or 61,920,000 more than our domestic production. The attractive oil producing regions of the world have been closed to the entry of America. All of these areas with the exception of Mexico and parts of Central and South America lie within British and French possessions or spheres of influence. British and British Dutch nationals practically control all the world's petroleum industry that is not controlled by our own companies. Great Britain and British nationals are alive to the fact that production scattered all over the world will be the dominating factor from now on and it is their plan to secure concessions or other rights covering these probable and possible oil producing

areas. Unless Americans are encouraged to go abroad, future oil production will all be in the hands of British nationals within the next very few years. No greater or more lasting and far reaching service can be rendered to this country at the present time than securing for American citizens their rightful participation in the development of all the world's resources of petroleum."

Capital

It should be borne in mind that the oil shale industry is not a "poor man's game" in the sense that a small amount of capital invested will quickly bring fabulous returns. On the contrary, it is distinctly a "rich man's game," in the sense that a large amount of capital must be invested before there is any return whatever. The smallest unit—and that only as a starter—should be of 100 tons daily capacity to cost approximately $100,000. This unit should be added to, till at least 500 tons a day are reached and 1,000 would be much preferable. Another phase that should be emphasized is that the oil shale industry is a low-grade industry, of large tonnage, of continuous operation, with automatic machinery, and large output. Workmen need only to be "broad in the back." The brains must be supplied in the office. The greatest need of the industry at the present moment is capital to open the deposits, erect retorts, establish refineries, organize distributing agencies, and, in brief, to establish the industry on a commercial scale and a paying basis. The small investor should use the

utmost caution before investing in the stock of newly organized oil shale companies. The fundamental facts about the industry are so stupendous and are so officially put forth that the dishonest promoter can easily excite the cupidity of the unthinking investor. The investor should investigate carefully the standing of the officials and fully realize that he is engaging in a long pull project and that no returns are possible until the plant is completed in every respect and operating steadily. Underfinancing is also a danger that must be faced, e. g., if a company needs \$100,000, can secure only \$50,000, and has a plant only half completed, the entire investment may be lost.

CHAPTER VIII

SUMMARY

The oil shale industry has reached its greatest development in Scotland, where it was established in 1850. Next in importance comes France and then New South Wales.

Significant Features

In Scotland the technical and chemical problems of the industry have been carefully solved and, on the whole, the industry has been commercially profitable. The Scotch shale beds are comparatively thin, irregular, steeply inclined, deep, and expensive to work.

The oil content of the Scotch shales is now much less than formerly and the shale could not be worked profitably if it were not for the ammonium sulphate produced.

The increased demand for petroleum, the exhaustion of producing wells in the near future, and the enhanced price will result in competitive shale oil which will be produced from an inexhaustible supply of shale by cheap mining and efficient retorting.

The oil shale industry is not, in ordinary parlance, "a poor man's game." The technical and

chemical problems are numerous and require a high grade of scientific ability for their solution.

A plant of 1,000 tons daily capacity is as small as can be operated permanently and successfully, as the profits will depend chiefly on the large tonnage handled. In this respect, the oil shale industry bears the same relation to the oil that Utah Copper and the other copper porphyries bear to copper.

An investment of $500,000 is as small as can be safely counted upon to make a single project successful.

Labor is cheaper in Scotland than in the United States; the Scotch shale produces more ammonium sulphate than the Colorado shale. These are the only factors favorable to the Scotch shale; all other elements that enter are distinctly in favor of American shale.

Oil shale land is primarily acquired from the government under the Federal mining laws governing placer mining claims. At the present time, however, all shale land advantageously situated has been filed on or is owned by individuals or corporations.

Oil shale itself varies in different localities and in different strata in the same locality.

The oil shale industry is a comprehensive one and embraces features of mining, shale reduction, mechanical engineering, oil refining, applied chemistry, and the business involved in marketing the products.

Little manual labor is required, as automatic machinery does the bulk of the work.

Variation in the estimated cost of producing crude shale oil is caused by the exclusion or inclusion, in the estimate, of the by-products. Another cause of difference is the high or low estimate of the amount of shale oil that can be extracted from each ton of shale. Inasmuch as there is known to exist in the De Beque-Parachute district a large commercial supply of shale that will produce a barrel of crude oil—42 gallons—to the ton of shale and such shale deposits have the economic advantages of altitude, nearness to water, accessibility, and proximity to transportation, one is on a safe, conservative basis to estimate a barrel of oil to the ton of shale. The amount of shale of this grade now available will last for many years.

The early success of the industry will depend upon the cost of production and marketability of its main products—not upon its by-products—no matter how fascinating these by-products now appear.

Black powder will probably be more efficient in mining shale than dynamite.

Some shales contain sulphur and hence produce an inferior grade of oil, but Nevada, Colorado, and Utah shales are generally free from sulphur, or carry very little, and produce a high grade of crude oil easily amenable to refining.

Gasoline from Colorado oil shale does not be-

come dark, off-color, or otherwise deteriorated by standing. Samples refined by the Wells process are known to have kept their color for more than a year.

Crude shale oil is a manufactured oil and consequently can be kept virtually free from impurities. Tests thus far made indicate that the great majority of shale oils produced, when made under proper conditions, are of a quality greatly superior to the oil produced by wells. The quality of oils produced from wells varies greatly. Impurities that prove injurious to the quality of the oil are present, to a greater or less extent, in almost all well oils. The majority of shales do not contain impurities to such a degree as to affect the quality of the oil produced. Kerogen is the oil producing matter in the shale.

The oil produced from 4.44 tons of shale (42 gallons to the ton) is equivalent to the heat effect of one ton of coal of 11,000 B.t.u. calorific value.

The heat value of 2.41 tons of oil shale (42 gallons of oil to the ton) is equivalent to the heat value of one ton of coal of 11,000 B.t.u. calorific value.

Colorado massive shale will average 18 cubic feet to the ton; when broken, 30 cubic feet to the ton in volume.

A ton of shale (42 gallons) will produce an average of 2,500 cubic feet of gas. A 400-ton plant would therefore produce daily 800,000 cubic feet of gas. Ninety-four pounds of coal are equivalent

to 1,000 cubic feet of gas. Consequently the 800,000 cubic feet of gas produced daily by a 400-ton distillation plant would be equivalent to 74,200 pounds of coal, or 37.6 tons.

The minimum capacity of a distillation or retorting plant to include crushing, retorting, gasoline absorption, and ammonium sulphate units, should be 100 tons daily. The cost of such a plant would be approximately $100,000. Additional 100-ton units could be installed for $50,000 each. These estimates are made for retorts which have a capacity of 1.5 tons to the charge. From five to six charges can be made daily, resulting in a daily capacity of from 7.5 to 9 tons a day. A bank of 16 retorts is roughly assumed to be of 100 tons daily capacity. A 100-ton plant should be regarded as only a starter. A thousand tons should be regarded as a minimum commercial size.

The minimum size for a refinery, to include a paraffin wax plant should be 400 barrels daily, and would cost approximately $350,000. This also should be regarded as only a starter. A refinery of 1,000 barrels daily capacity should be regarded as the minimum capacity for continuous commercial operations. One refinery in the De Beque-Parachute district, for example, would fill the needs of several distillation plants.

At Tulsa, Oklahoma, the cost of refining is 38 cents a barrel in the Cosden and Company plant of 40,000 gallons daily capacity. In a two months'

test run by the Wells process at this plant the cost was 27 cents a barrel.

A plot of ground 200 by 300 feet is sufficient for a distillation plant of 400 tons daily capacity.

Only about 60 per cent of the gas ordinarily produced would be needed to supply power for the distillation and refinery plants. The remainder, 40 per cent, would be available for other purposes.

Ore is crushed, but shale should be broken. This is accomplished in Scotland by the use of spiked rolls. Spikes 2.5 inches at the base and 3 inches long are arranged spirally in rolls and are removable. In Scotland all shale smaller than one inch is left in the mine. American shale breaks well.

Sticking of shale in the retort, in some cases, causes serious trouble. Tests show that if the temperature is kept below 850° sticking does not occur in Colorado shale, but they do stick if the temperature goes above that point. Samples of Nevada and Utah shales have been tried that do not stick up to 1200°. Mixtures of Nevada and Colorado shale seemingly do not stick. In Parachute creek the black, rich streak sticks at 850°, but if mixed with poorer shale, (35 to 40 gallons to the ton) in the proportion of 100 pounds of the poorer to 400 pounds of the richer, the product does not stick below 1,000°. However, sticking is prevented by the introduction of steam, provided the steam is injected early enough in the process.

Crude petroleum from wells varies widely in

different fields. Crude shale oil is virtually a manufactured article. It may be spoiled, in the manufacture, for refining into valuable products. Also, good shale oil may be subjected to an inefficient method of refining and become commercially unprofitable.

In Scotland two men working together produce 8 tons (2,240 lb.) a day at a cost of 5 shillings, or \$1.25 a ton. Reduced to a ton of 2,000 lb. this would be \$1.11 a ton. The Scotch miner works on a seam only 6 or 7 feet thick, hundreds of feet below the surface under unfavorable conditions. If the Scotch miner, under unfavorable conditions, can mine four tons of shale, certainly the American miner in our shale beds so easily worked can produce twice that amount. It is certain, then, that our estimate of \$1.25 a ton for mining is large enough and in practice will surely be reduced.

The quantity and quality of oil that can be produced is variable, according to the skill and intelligence of the operator, the method used, the type of retort, the rate of heating, the amount of heat applied, the introduction of steam, and many other details. In short, oil produced from shale may or may not show good results, from no fault of the shale. Good shale, subjected to poor methods, may give oil that fails to yield to refining. Hence follow conflicting opinions as to the character of the shale oil produced and the results from refining. Retorting shale and refining oil are not fool proof processes.

A frequent distinction is made between American and Scottish shale, as if there were only two varieties—one American and one Scotch. It should be clearly understood that there is a great variety of American shales—as great a difference between them as between any one of them and the Scotch shale. Hence varieties of American shale may require different forms of treatment.

In Colorado alone the available oil from shale is conservatively estimated at 58,080,000,000 barrels. To produce this would require the work of 100 plants each producing 2,000 barrels daily for 800 years. In Utah the supply is sufficient to last 550 years.

The value and extent of oil shale deposits can be accurately determined by diamond drilling.

A satisfactory retort for American shales is the crux of the oil shale industry.

One ten-foot seam of oil shale which yields a barrel of oil to the ton will produce seven times as much oil to the square mile as the average production from proven well-oil ground.

The United States produces two-thirds of the world's output of oil, but this is insufficient for her needs.

The chief elements of a complete oil shale plant are:

a. Mining equipment
b. Breaking machinery
c. Retorts
d. Condensers

e. Refining and cracking plant
f. Wax plant
g. Sulphuric acid plant
h. Storage and transportation facilities

In general the favorable features of the oil shale industry are:

a. The enormous extent of the deposits
b. The great thickness both of the medium and high grade shale
c. The horizontal position of the strata and their height above the level of the creeks—a combination that affords cheap mining
d. Adequate water supply for the condensing and cooling systems both for the distilling and refining plants
e. Accessibility and nearness to railroads and markets
f. The great richness of the shale

These features combine to make the oil shale deposits of the United States the most valuable deposits of their kind in the world. In the minds of those men who are best informed on the technical and business phases of the oil shale industry, it has passed the experimental stage and "has arrived."

CHAPTER IX

OPINIONS

"All the statistics available to me dealing with oil production and crude oil consumption, the decline of the present proven oil territory, and the possibilities for new oil wells, lead to the conclusion that it is only a matter of a few years under existing conditions until there must be developed other sources of hydrocarbon oils than the oil wells themselves. These sources are limited to high volatile coals, cannel coal, lignites, and oil shales. Of these possibilities the oil shales offer by far the greatest promise because, in the first place, there are tremendous deposits of these shales which are easily accessible, and, in the second place, because the shales will yield large volumes of oil when destructively distilled.

Van H. Manning, Director, U. S. Bureau of Mines, Letter to the Author

"In the development of any large industry, such as the oil shale industry gives every indication of becoming, there is always a considerable interval between the inception of the industry and the time when it becomes a strong commercial factor. These considerations lead me to believe that shale oil

developments should be undertaken at once and that the expenditure of money in material in oil shale plants will in no wise be an unpatriotic venture. It is high time that some one did the pioneering in this industry and to the pioneer in any such enterprise always belongs a great deal of credit. I assure you that this Bureau wishes to encourage in every way feasible the undertaking and legitimate development of the oil shale industry.

"I think you will agree with me that the oil shale industry is essentially a low grade manufacturing proposition involving the investment of a large amount of capital and skillful engineering, as well as technical ability, in the erection and operation of shale plants. I believe that the large oil shale operator with a staff of technical experts will be able to operate at a profit under the present market conditions and prices of labor, material and products obtainable from oil shale, but I am even more certain that the small operator will be almost certain to meet with a failure. I trust that you will take every opportunity to impress these facts upon the people of Colorado who are contemplating investing in or engaging in the oil shale industry."

"The question is being asked daily what the country is going to do when our petroleum resources are exhausted. We have as yet untouched our great reserves of shale that contain oil. These shales are found in many parts of the

United States, and tremendous reserves are known in Colorado, Utah, and Wyoming. Some of our shales are much richer than the Scotch shales, and are conservatively estimated to contain many times the amount of oil that has been, or will have been, produced from all the porous formations in this country.

Van H. Manning, Director, United States Bureau of Mines, Bureau of Mines Yearbook, 1917

"To obtain the oil from oil shale it is necessary to heat the shale in great retorts. The oil is the result of destructive distillation and is driven off in the form of vapor and is later condensed by cooling. As stated above, this process has never been used in this country because of the lack of necessity, for our oil reserves are great, and it would not be commercially economical to invest money in retorts for distilling oil from shale that would have to compete with the crude oil obtained by other methods. But this condition will not last forever. In fact, it is thought that it will be only a very short time until the oil shale industry will be one of magnitude."

"During the year the Bureau of Mines has been particularly interested in the vast deposits of oil shales in Colorado and Utah that have been disclosed by the field investigations of the Geological Survey. Because of the threatened shortage of petroleum from oil fields in the future, these shales are considered to be the principal reserve of this country for the future supply of gasoline

and other petroleum products. Consequently, much attention has been given to preliminary investigations of the richness of the shales, and a detailed study is being made of the best methods of obtaining oil from the shales, the character of the shale oils and the proportions of the various oil products and by-products obtainable by different methods of distillation. The investigations made lead to the belief that it is now commercially feasible to work selected deposits of shale in competition with oil from oil wells, and that these oil shale reserves can be considered of immediate importance to the oil industry. Several commercial plants for mining and treating the shale have been planned and the Bureau of Mines will closely follow the developments. It is believed these investigations have already demonstrated a reserve of oil adequate for all future needs of the Navy."

"Investigation of Oil Shales," Seventh Annual Report of the Bureau of Mines, Van H. Manning, Director, to the Secretary of the Interior, for the Fiscal Year Ended June 30, 1917

Mr. Lane said, in reply to a Senate resolution regarding gasoline, and referring to the shale beds of the country: "The development of this enormous reserve supply simply awaits the time when the price of gasoline or the demand for other distillation products warrants the utilization of this substitute source. This may happen in the future. At all events these shales are likely to

Franklin K. Lane, Secretary of the Interior

be drawn upon long before the exhaustion of the petroleum fields.''

''It is true that the Government, and particularly the Geological Survey, has spent considerable time and money in the last few years in a study of the oil shale deposits. As a result of the field examinations made from 1913 to 1916, it has been clearly demonstrated that the latent potentiality of the oil shale of this region as a source of petroleum is enormous. It is also known that there is locked up in these shales a vast amount of nitrogen which can be recovered as a by-product in the refining of the shale and used in the manufacture of fertilizers and explosives.''

George Otis Smith, Director, U. S. Geological Survey, in a Letter to Congressman E. T. Taylor, September 8, 1917

''The day that some company undertaking the production of oil through the distillation of oil shales in this country proves, through actual practice, that oil may be produced successfully and continuously on a commercial scale at its plant, a new page will be turned in the industrial history of the United States. The significance of the first genuine production at a profit is hardly likely to be overestimated. Such a demonstration will tend to limit maximum petroleum prices in competing areas and to reassure the American Republic as to its oil supplies.

Extract from Letter from George Otis Smith, Director, United States Geological Survey, December 19, 1918

''These circumstances justify the interest dis-

played by the public as well as the companies that are honestly undertaking the task of designing and constructing plants while the industry is yet in its experimental and, therefore, uncertain stages. As soon as the oil is produced successfully on a commercial scale, the industry is destined to expand rapidly, unless interfered with by the discovery of an important oil field between the Rockies and the Sierra-Nevada-Cascade Range barrier. Its normal expansion, however, will probably not be so rapid as to affect petroleum prices especially.

"Although the conditions of shale mining in northwestern Colorado and northeastern Utah are in general widely different from those in Scotland and France and to a certain extent from those in Australia, and though the composition of the Green River oil shales undoubtedly differs somewhat from the Old World deposits, much should be gained by the utilization of the experience and methods of those who have long been engaged in the industry with financial success. In the attack on the technological questions of oil extraction, the United States Bureau of Mines is extending constructive co-operation as well as cordial interest.

"Notwithstanding the work done over sixty years ago in the distillation of shales and coal, the proposition of producing oil on a large scale by shale distillation is in fact essentially new in this country. The problem is bound to attract

more attention as the demand for petroleum continues to gain on the supply from wells in the United States.

"The generously encouraging attitude of the Federal Government and of the States toward the establishment of new industries, and especially toward the development of mineral deposits, makes possible the perpetration of numerous frauds under guise of oil-shale promotion. It is the duty of officers like yourself, who are on the ground and who are in a position to gather knowledge enabling you to discriminate between the fraudulent promoter, on the one hand, and the honest experimenter and developer, on the other, to expose the frauds and put in motion the machinery which, under State and Federal laws is, in many cases at least, sufficient to put an end to such business. On the other hand, it is as important that honest, well-organized companies, with promising plans and methods, should be helped by all wise and legitimate means."

"The position of the United States in regard to oil can be characterized as precarious. Using more than one-third of a billion barrels a year, we are drawing not only from the underground pools, but also from storage, and both of these supplies are limited. In 1918, the contribution direct from our wells was 356,000,000 bbl., or more than one-twentieth of the amount estimated by the Survey geologists as the content of our underground reserve; we also drew from storage

George Otis Smith, Director United States Geological Survey. Paper before the American Institute of Mining and Metallurgical Engineers, January, 1920

24,000,000 bbl., or nearly one-fifth of what remains above ground. Even if there be no further increase in output due to increased demand, is not this a pace that will kill the industry? Even though we glory in the fact that we contributed eighty per cent of the great quantity needed to meet the requirements of the Allies during the war, is not our world leadership more spectacular than safe? and even though the United States may to-day be the largest oil producer and though it consumes nearly 75 per cent of the world's output of oil, it is not a minute too early to take counsel with ourselves and call the attention of the American geologists, engineers, capitalists, and legislators to the need of an oil supply for the future."

"The investigation, with mapping, of the oil shale in the West, begun by the Geological Survey in 1913, largely as a measure of preparedness, has yielded a volume of information as to the distribution, richness, character, composition, and possibilities of these shales, which is now proving invaluable in the foundation of a new industry that is sooner or later to be of very great economic importance to the country. The many experimental plants now in operation or under construction for producing oil from these shales for commercial use should soon demonstrate whether, as was expected, the moment has already arrived

when the production of shale oil will not only regulate the price of gasoline, but will assure an almost unlimited supply of that essential fuel. Conservative estimates of the quantity of crude oil that may be recovered from beds of shale three feet or more in thickness and capable of yielding twenty-five gallons or more of oil to the ton of shale (some beds will yield as high as seventy gallons) indicate that the shales of northwestern Colorado and northeastern Utah alone can produce over ten times as much oil as has been recovered from oil wells in the United States since the first commercial oil well was drilled in Pennsylvania in 1859. What the full possibilities of these shales may be in the way of by-products other than gasoline remains to be seen. It is not impossible that new products or preparations yet to be discovered in the experimental laboratory may be of signal importance to the country and may radically affect the commercial success of the industry. The tests already made indicate that the shales will furnish material for dyes, fertilizers, rubber substitutes, paving material, drugs and lubricants."

"The Investigation with Mapping of the Deposits of Oil Shale in the West," Thirty-ninth Annual Report of the Director of the United States Geological Survey, George Otis Smith, Director, to the Secretary of the Interior, for the Fiscal Year Ended June 30, 1918

"Granted the utmost in the development and use of the remaining supply of petroleum, economic pressure from oil shortage will still be not far distant. Attention turns, therefore, to sources

of supply other than the porous rocks of oil fields thus far exclusively exploited in this country. It is of great significance, therefore, that within the past five years geological explorations on the part of the United States Geological Survey have definitely established the existence of vast areas of black shale in Utah, Colorado and Wyoming, much of it capable of yielding upon distillation around fifty gallons of oil, 3,000 cubics of gas, and seventeen pounds of ammonium sulphate—the whole constituting an oil reserve aggregating many times the original supply of petroleum."

"Development of Oil Shales"—"Petroleum, a Resource Interpretation," by Chester G. Gilbert and Joseph E. Pogue, Smithsonian Institution, United States National Museum, Bulletin 102, Part 6, 1918.

"These shale areas will be developed in time on as safe and sane a basis as our coal mines of to-day. When that time arrives, the remains of oil prospecting will have fled and the whole complexion of oil production will change. It will, literally, be oil mining with steam shovels in open pits and glory holes; and, later, tunnels and adits. There will be no lack of oil products for several generations to come, but the true oil fields of to-day will probably disappear within another generation and be replaced by oil mines."

"The Oil Shale Areas," Dorsey Hager, "The Search for New Oil Fields in the United States," Engineering and Mining Journal, New York City, January 5, 1919.

"Is the United States facing a gasoline famine?

Shall we be required to forego automobiling except to meet the stern necessities of war and of utilitarian traffic? Are our petroleum fields showing signs of exhaustion?

"Billions of Barrels of Oil Locked Up in Rockies," by Guy Elliott Mitchell, of the United States Geological Survey, in the National Geographic Magazine for February, 1918.

"The output of petroleum has not yet begun to diminish; statistics show that it is still increasing; yet the downward trend of production from the present oil fields is plainly in sight.

"The war has made a sudden and enormously increasing demand on the oil fields of America, and though the industry has never been so feverishly active as it is now and the output never so large, the truth is that the demand has not been entirely met. And the demand will be ever increasing, ever pressing.

"Many of the host of larger vessels that we are now building will be equipped with oil-burning furnaces, and the vast swarm of airplanes that we are building, as well as the thousands of automobiles and trucks that we are turning out, will consume an enormous quantity of gasoline. Yet no great new oil regions comparable with the Mid-Continent or California fields are being discovered, and it is questionable whether any will be, for our oil geologists have pretty thoroughly combed the accessible oil areas. What then, is the answer?

"It is just at this juncture that we have made a discovery that has disclosed what is undoubtedly

one of our greatest mineral resources—one that should supply the needs of the war, and that for generations to come will enable the United States to maintain its supremacy over the rest of the world as a producer of crude oil and gasoline and incidentally of ammonia as a highly valuable by-product. We have discovered that we possess mountain ranges of rock that will yield billions of barrels of oil.

"For many years travelers going west through the Grand River valley of Colorado and into the great Uintah basin of eastern Utah have looked from the windows of their Pullman cars on the far-stretching miles and miles of the Book Cliff mountains, little realizing that in these and adjoining mountains, plainly exposed to view, lay the greatest oil reservoir of the country—the oil shales of Colorado, Utah, Wyoming, and Nevada.

"These shales, it is true, were known to yield oil. Campers and hunters in building fires against pieces of the rock had been surprised to find that they ignited and burned, and investigation showed that they contained oil. This fact was looked upon, however, as only another of the natural curiosities of the great West and little or no attention was paid to it because of the seemingly inexhaustible pools of crude petroleum found elsewhere under great areas.

"In connection with its investigations of the undeveloped mineral resources of the country the United States Geological Survey has recently

made special studies and tests of these oil rocks and has brought to light two important facts: first, that our Western shales are phenomenally rich in oil, and second, that in foreign countries; particularly Scotland, much inferior shales are to-day successfully mined and worked as a source of oil and other commercial products. The industry in Scotland is seventy years old and is still in a highly flourishing condition."

"In Colorado alone there is sufficient shale, in beds that are three feet or more thick, and capable of yielding more oil than the average shale now mined in Scotland, to yield about 20,000,000,000 barrels of crude oil, from which 2,000,000,000 barrels of gasoline may be extracted by ordinary methods of refining, and in Utah there is probably an equal amount of shale just as rich. The same shale in Colorado, in addition to the oil, should produce, with but little added cost, about 300,000,000 tons of ammonium sulphate, a compound especially valuable as a fertilizer. The industry requires a large equipment of retorts, condensers, and oil refineries, as well as of mining machinery, so that it cannot be profitably handled on a small scale."

Dean E. Winchester, U. S. Geological Survey, Bulletin 641-F, Page 141.

"During the last year, the United States has produced a little over 1,000,000 barrels a day of crude petroleum, a total of 376,000,000 barrels, according to the government's preliminary figures. In addition to this, there has been imported

from Mexico, about 60,000,000 barrels. The petroleum industry in this country, therefore, used during the last year a total of approximately 436,000,000 barrels. Apply 8.54 per cent of increase, and one has 37,235,000 barrels additional required during the present year in order to meet the increased demand, based on the actual figures of past experience. If this percentage of increase continues—and there is no reason to doubt that it will—then five years from now (in 1925), the petroleum industry in this country will need approximately 670,000,000 barrels, or an increase of 225,000,000 barrels as compared with 1919. These figures give rise to a natural query as to where this enormous quantity of crude oil is to come from.

President Walter Clark Teagle, of the Standard Oil Co. of New Jersey

"What is the Standard Oil doing toward increased production? The producing department is planning a most active campaign of exploring and development outside of the United States. The policy of the company at present is to be interested in every producing area in the world, provided of course that interests can be secured on a basis that would seem to hold out the possibilities of success, and where the lives and properties of American citizens will be respected. We are now operating in Roumania and investigating prospective oil producing properties in Russia, Galicia, and elsewhere in Europe. At this moment, we have a party of practical oil men and

geologists in South America and another expedition is making preparations for a survey of another part of that country.

"In Peru, the International Petroleum Co., Ltd., is arranging for an increase of 100 per cent in its drilling campaign, and to the north of us, The Imperial Oil Co., Ltd., is most energetically developing production in western Canada. It has a number of 'wild cat' wells drilling; also, a rig-up with a crew in winter quarters within the Arctic circle, 1,200 miles from the nearest railroad."

United States Geological Survey

The report of 1914, made by the United States Geological Survey, under the direction of E. G. Woodruff and David T. Day, in contribution to Economic Geology, United States Geological Survey, Bulletin 581, year 1914, says:

"The oil shale in western Colorado and eastern Utah constitutes an undeveloped reserve of petroleum to which attention was directed by the Geological Survey of 1901. The net result of the examinations already made is that these oil shale areas in Colorado contain a latent petroleum reserve whose possible yield is several times the total remaining supply of petroleum. The gasoline content of the petroleum that can be distilled from these shales can be conservatively stated in billions of barrels."

The prefatory remarks of Marius R. Campbell to the report of Dean E. Winchester, of United States Geological Survey, on oil shale in north-

western Colorado, published in Bulletin 641-F, United States Geological Survey, year 1916, says:

"For several years it has been known that some shale of the Green River formation in northwestern Colorado would produce oil when subjected to destructive distillation, but the yield of petroleum from the oil fields was so great that production by distillation did not seem feasible despite the fact that in Scotland such an industry has long been developed and is to-day paying dividends on a large investment.

"The United States Geological Survey has regarded this oil shale as a great reserve or undeveloped resource and one that would be developed as soon as demand for petroleum exceeded the supply. In anticipation of such an event E. G. Woodruff and David T. Day, in 1913, began an examination and made rough field tests to determine the richness of the shale. Although these tests were not entirely satisfactory they tended to confirm the general impression that this shale constitutes a source of oil which sooner or later will be called into use. Of course, no prediction could be made as to the date when this additional supply would be needed, but the Survey felt justified in continuing the geological investigation in order that when the time of need arrived it would have first-hand information on the richness and quantity of the shale for distillation. Accordingly the field examination was continued during

the summers of 1914 and 1915 by Dean E. Winchester, who devised a more efficient portable apparatus for determining not only the quantity of crude oil in the shale but also the amount of gas and ammonium sulphate (fertilizer) that might be obtained as a by-product and sold. The experiments by Mr. Winchester confirmed results of the work done in the previous year and indicated even more strongly that a great quantity of high class fuel is locked up in this shale.

"At the present time owing to the great increase in the consumption of gasoline and the failure to discover large new oil fields, it seems that the day is approaching when this additional supply will be needed and the public will demand all the information in possession of the Survey on the subject. I feel confident that this report of Mr. Winchester's will supply much of the data needed to establish and develop the oil shale industry of this country.

"Mr. Winchester's results, which have been corroborated by tests made in the laboratory of the Bureau of Mines, show that the quantity of oil that can be derived from such shale ranges from less than one gallon to ninety gallons to the ton of shale. Mr. Winchester, as a result of field tests, estimates that in Colorado alone there is enough shale to produce twenty billion barrels of oil, and it seems probable that in actual practice a greater yield than this can be obtained. He

also estimates that three hundred million tons of ammonium sulphate can be recovered as a by-product in the manufacture of this oil.

"In 1908, according to Ells, the oil shale industry of Scotland employed eight thousand men, of whom nearly four thousand were miners. The average yield of crude oil per ton of shale was 24.6 gallons to the short ton. The operations paid dividends in spite of this low yield. The cost of mining shale in Scotland is reported by the same author to be $1.00 per ton; the cost of distilling crude oil from shale is 40 cents per ton, and the cost of making ammonium sulphate from the shale is 46 cents per ton. All mining in Scotland is underground and in many of the mines the shale dips at angles of from 30 to 60 degrees, and there are numerous faults which greatly increase the cost of mining. At many places in Colorado, however, the rich shale has only a slight over-burden and can be mined with a steam shovel.

"In Colorado alone there is sufficient shale in beds that are three feet or more thick and capable of yielding more oil than the average shale now mined in Scotland. We estimate the yield at twenty billion barrels of crude oil from which two billion barrels of gasoline may be extracted by ordinary methods of refining.

"The same shale, in addition to the oil, should produce with but little added cost, about three hundred million tons of ammonium sulphate, a compound especially valuable as a fertilizer."

A conviction tantamount to prophecy appears in the statement of former United States Oil Administrator, M. L. Requa, in Senate Document No. 310, in which he says:

M. L. Requa

"We dare not retrench. It means the slowing down of our industries; it means a post-war competition which we shall not be able to stand. Europe is organizing for industrial competition such as the world has not yet seen, therefore conservation under present conditions means retrenchment. What is the substitute? It must be oil—another kind of oil, perhaps, but a petroleum or rock oil. Where must we look for it? To the shales and oil-bearing coals."

CHAPTER X

THE FUTURE

The Future

Rapid as has been the increase in the demand for crude oil and its products, yet the future holds out even greater expectations. There are now approximately 7,500,000 internal combustion engines in the United States. In ten years this number will very likely be doubled to 15,000,000. In spite of the phenomenal growth of the automobile industry there is no indication of a slackening. Good authorities assert that the next five years will show even a greater increase, or fully 10,000,000 motor cars in operation. The Ford plant alone will manufacture 500,000 tractors in 1920. The United States Shipping Board has ordered that all vessels greater than 5,000-ton dead weight shall be oil burners and has contracted for 31,000,000 barrels of fuel oil for 1920. France will require 8,400,000 and Italy 336,000,000 barrels of oil in 1920. The potential demand for oil in the United States by 1927 is estimated at 800,000,000 barrels.

The normal annual increase in the demand for petroleum is, according to President Teagle, of the Standard Oil Company of New Jersey, 8.54

per cent. Apply this for the coming five years and we find that in 1925 we shall need an annual supply of 650,000,000 barrels, or an annual supply of 273,000,000 barrels above the production of 377,000,000 barrels in 1919. To make a bad situation worse, it is estimated that by 1927, the potential demand will be 800 million barrels, and the underground supply well nigh exhausted. No oil man is optimistic enough to predict that wells alone can be depended upon to produce this amount. If not, then on what must we rely? On our raw material—oil shales.

Possibilities of the Shale Industry

Inasmuch as the oil shale industry has been in operation in Scotland since 1850—seventy years —and has met and overcome technical, trade, and economic obstacles, it seems a mere matter of common sense for the pioneers of the industry in Colorado first to follow the well known and successful methods of Scotland; to adapt these methods to Colorado conditions, and then to improve them as far as possible by methods not now known. Besides, the production of crude oil, gas, and ammonium sulphate, other possibilities may open, e. g., the nitrogen may be reclaimed in a form for use in the manufacture of munitions of war; aniline dyes and flotation oils may be obtained; possibly producer gas, a substitute for rubber, and a long list of other possibilities, obtainable from any good encyclopedia, but it is simply a matter of good common sense for the pioneers in the indus-

try to focus their attention on the few staple products for which there is a general use, a steady demand, and a good market price. After this portion of the industry is stabilized there will be ample time and opportunity to develop the by-products.

Oil Shale Comes into Its Own

What have all these estimates to do with the oil shale industry? Simply this. Oil is the fuel of the future. Greater and greater demands are being made upon well oil. Great as are some oil pools, yet the average production falls short of the demand. The only recourse is to the vast stores of oil shale in which lie the potential elements of the future supply of oil. Oil shales are found virtually all round the world. The demand for oil is now strong enough and the price of crude high enough to warrant the commercial production of oil from shale. A number of plants are now nearing completion so that there is a likelihood that the industry will be on a commercial basis in the summer of 1920, or soon thereafter.

An Acute Situation

The rapid increase in the demand and use of petroleum together with the unsatisfactory production has caused students of the oil situation serious concern. War conditions clouded the matter. It was expected that, with the close of the war, consumption would decrease, but this has not been borne out by resulting conditions. Demand has increased. Domestic production has failed to keep

pace. The result is clear and certain. Industrial life, absolutely dependent upon petroleum, for without it not a wheel could turn, cannot depend longer upon the uncertain production of well petroleum. It must have a source of supply as certainly dependable as water or coal, a supply that can be counted upon year after year, else industrial life will falter. Such a source has been unexpectedly found in the enormous, world-wide deposits of oil producing shale.

Foreign Supply

It is possible that the United States may be able to draw upon foreign oil fields for its needed supply. Much dependence is placed upon supplies from Mexico, but political conditions there are unsatisfactory. To quote President Teagle, of the Standard Oil Company, "The situation is chaotic there." But the greatest obstacle to getting a foreign supply is the preeminence of Great Britain in the oil business. Her public men have long been familiar with the necessity of oil for every phase of industrial life. They have seen that Great Britain's supremacy depended upon oil more than upon any other single commodity. It is not too much to predict that when the real situation is uncovered it will be found that Great Britain controls, directly or indirectly, the great foreign oil fields of the world, and will take good care that her own economic needs are cared for.

The oil shale industry is essentially one of very

large tonnage, involving features of mining engineering, mechanical engineering, industrial chemistry, transportation, and distribution. No matter what difficulties may be encountered in the details of the business, the raw material available is virtually inexhaustible. When commercial plants are once established, there can be no doubt whatever of the permanence and continuity of the industry for generations. At the present writing (August, 1920) there are no fully established commercial plants producing crude shale oil and disposing of it on the market, either in the crude form or through any of its refined products. There is, however, pronounced activity in Colorado, Utah, and Nevada. A number of plants are projected, some are nearly completed, and some even are reported as completed, so that the summer of 1920 is likely to see one or more plants in successful commercial operation. A careful comparative study of well-oil production and oil consumption clearly indicates that the supply of oil must in the near future be looked for elsewhere than from wells. The well nigh inexhaustible supply of oil shale supplies the raw material.

Fundamental Character of the Industry

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